



Effects of Thermal Cycling on Control & Irradiated EPC 2nd Generation GaN FETs

NASA Working Group on Wide Bandgap
Semiconductor Power Devices

Richard L. Patterson, NASA GRC

Leif Scheick, JPL

Jean-Marie Lauenstein & Megan Casey, NASA GSFC

Ahmad Hammoud, VPL / NASA GRC

November 2013



Test Activity

- ***Wide Bandgap Devices***
 - Second Generation GaN FETs (EPC)

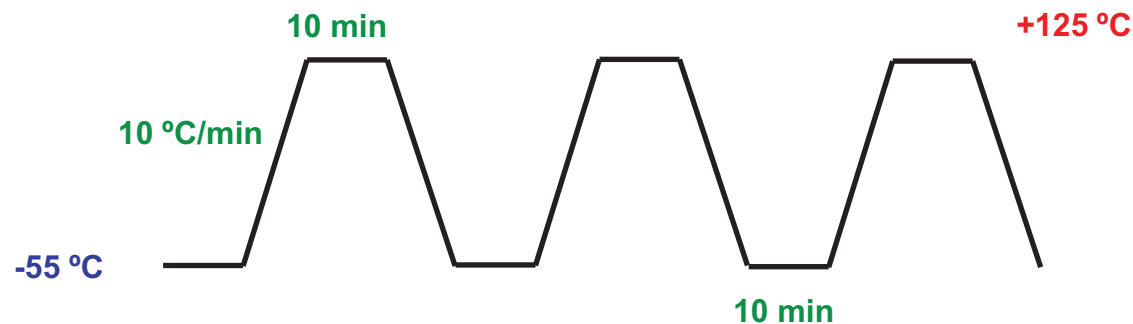
- ***Radiation Testing (JPL)***
 - TID (Total Ionization Dose)
 - SEE (Single Event Effect)
 - DDD (Displacement Damage Dose)

- ***Thermal Cycling (GRC)***
 - Control Samples
 - Irradiated Parts
 - Long-Term



Thermal Cycling

- **Cycling Profile:**
 - Total # of Cycles 1000
 - Temperature rate of change: 10 °C/min
 - Temperature range: -55 °C to +125 °C
 - Soak time at extreme temperatures: 10 min
- Parametric measurements performed on devices before, during, and after conclusion of cycling activity





Test Setup



Parameters Investigated:

- I-V Output Characteristics
- Gate Threshold Voltage, V_{TH}
- Drain-Source On-Resistance, $R_{DS(on)}$
- Pre, during, & post-cycling measurements at room temperature

Equipment Used:

- SONY/Tektronix 370A Curve Tracer
- Keithley 238 Source-Measure-Units
- LN-cooled Sun Systems Chamber



2nd Generation GaN FET

- **Efficient Power Conversion GaN transistors grown on Si wafer; <http://www.epc-co.com>**
- **Passivated-die form with solder bumps**



Sample die mounted on test structure



Test Parts:

- Radiation testing was performed by JPL

EPC2015 40V, 33A, 4mΩ		EPC2014 40V, 10A, 16mΩ		EPC2012 200V, 3A, 100mΩ	
Control Parts	Irradiated Parts	Control Parts	Irradiated Parts	Control Parts	Irradiated Parts
K7301	K7303	K6985	K7325	A4754	K7348
K7302	K7305	K6986	K7328	A4755	K7353
K7304		K7333	K7347	A4756	K7354
K7306		K7336		A4757	K7359
K7311		K7346		A4758	K7370
K7312		K7072		A4759	K7395
					K7396
					K7399
					K7364

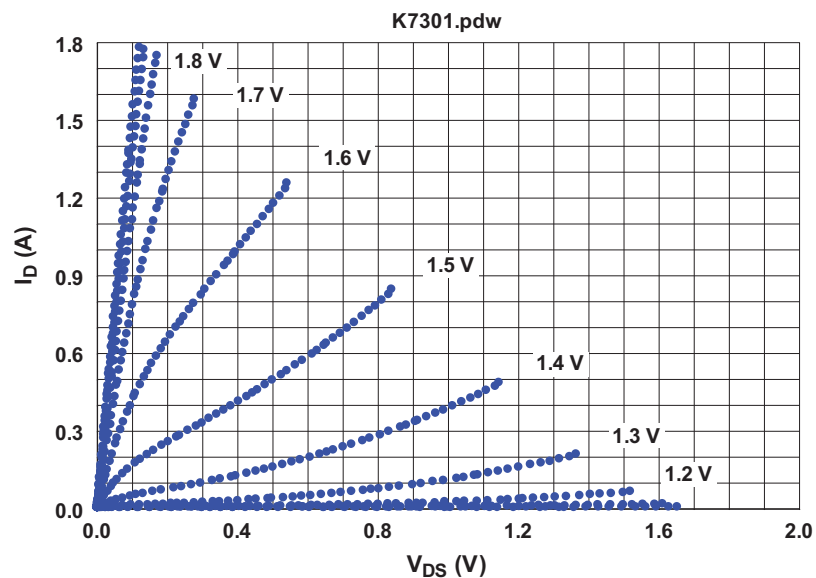
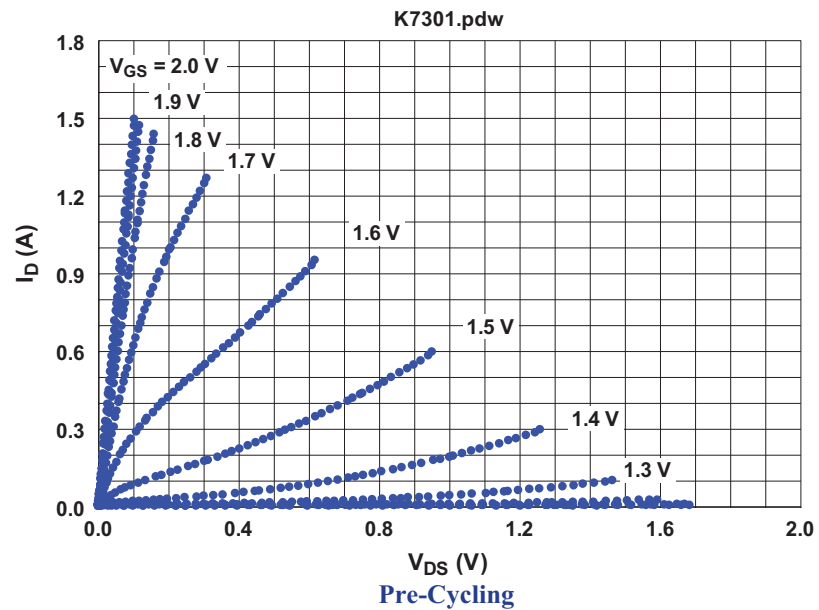


EPC2015 Enhancement Mode Power FET

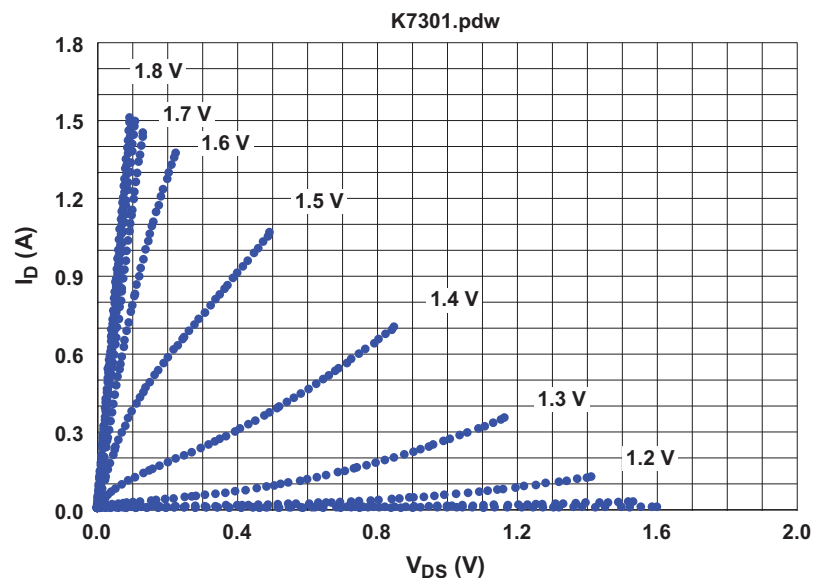
EPC2015 40V, 33A, 4mΩ	
Control Parts	Irradiated Parts
K7301	K7303
K7302	K7305
K7304	
K7306	
K7311	
K7312	



I-V Curves for K7301 (control EPC2015)



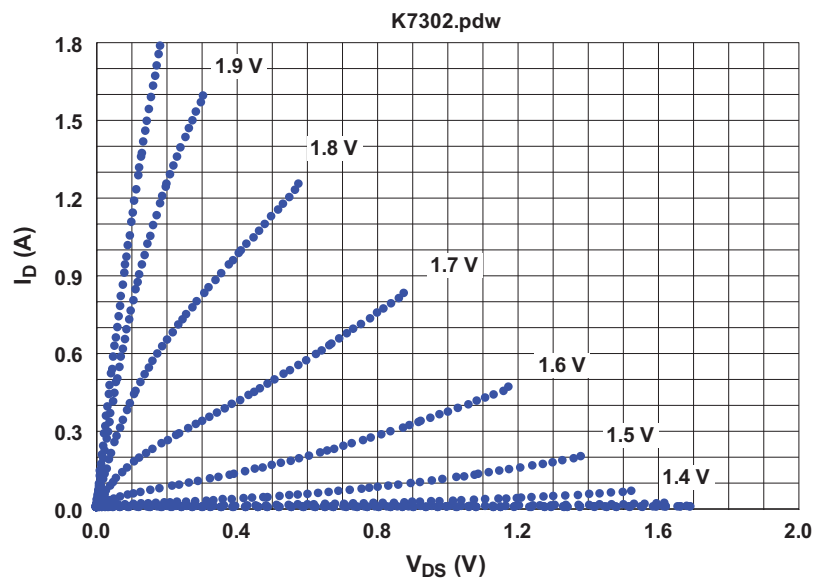
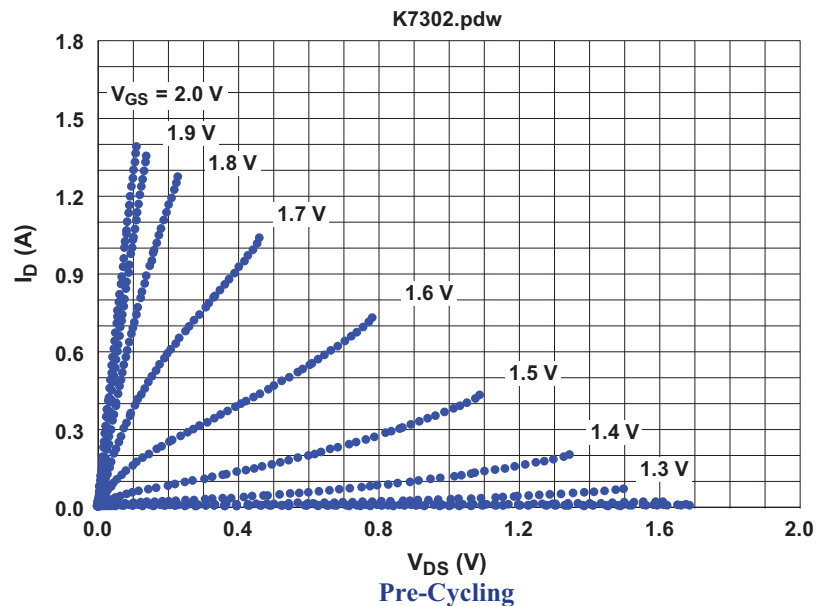
After 500 Cycles



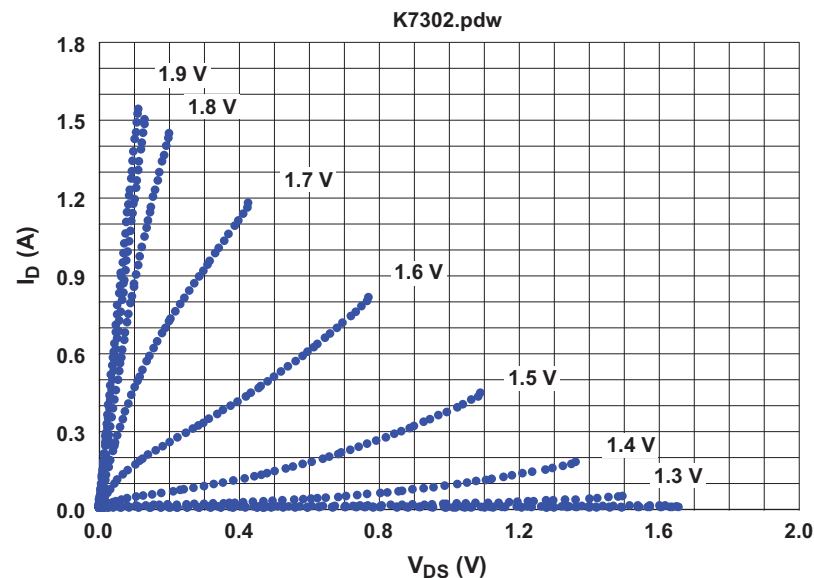
After 1000 Cycles



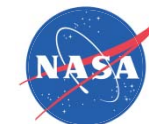
I-V Curves for K7302 (control EPC2015)



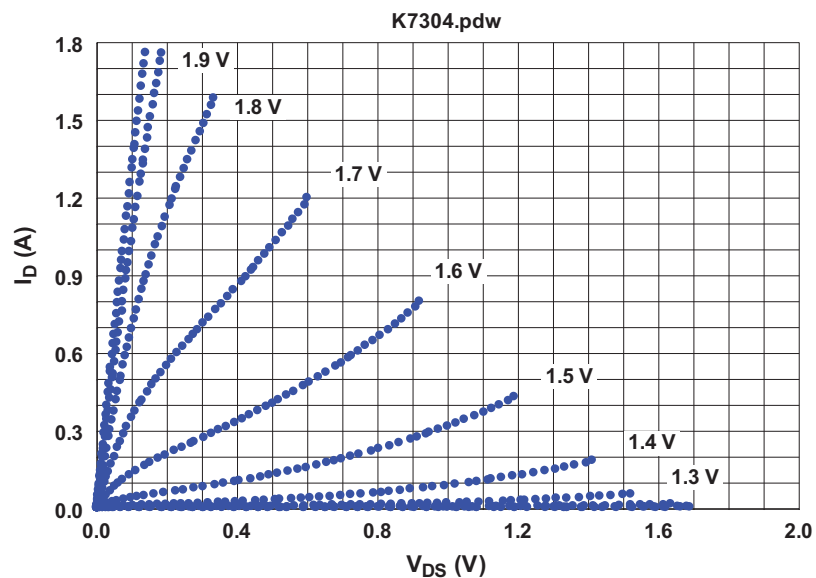
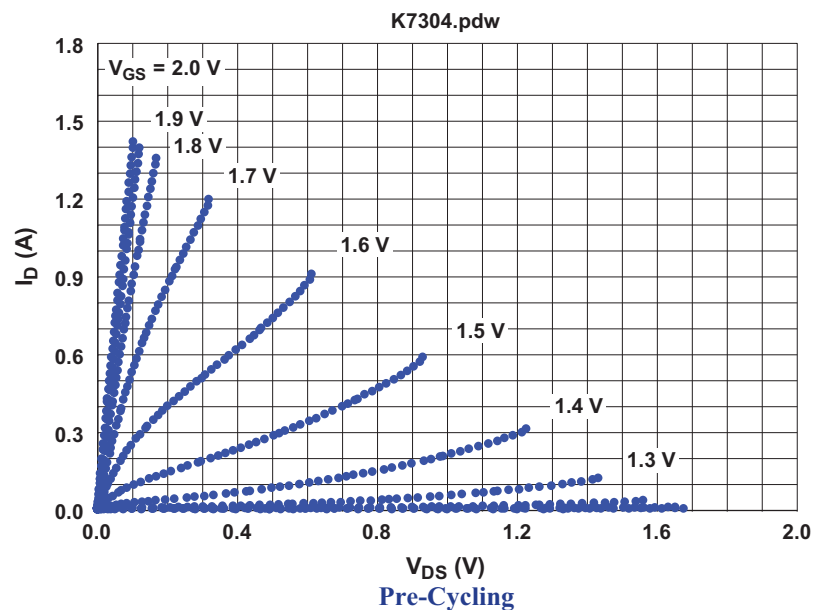
After 500 Cycles



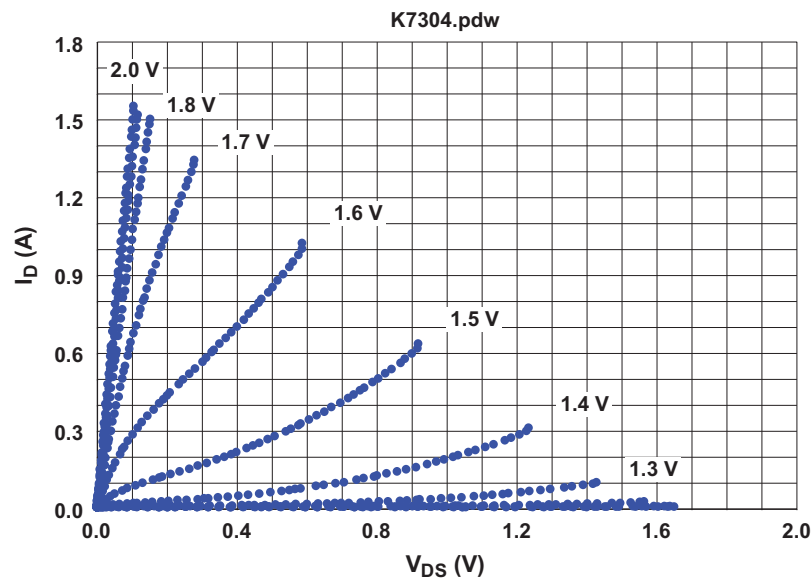
After 1000 Cycles



I-V Curves for K7304 (control EPC2015)



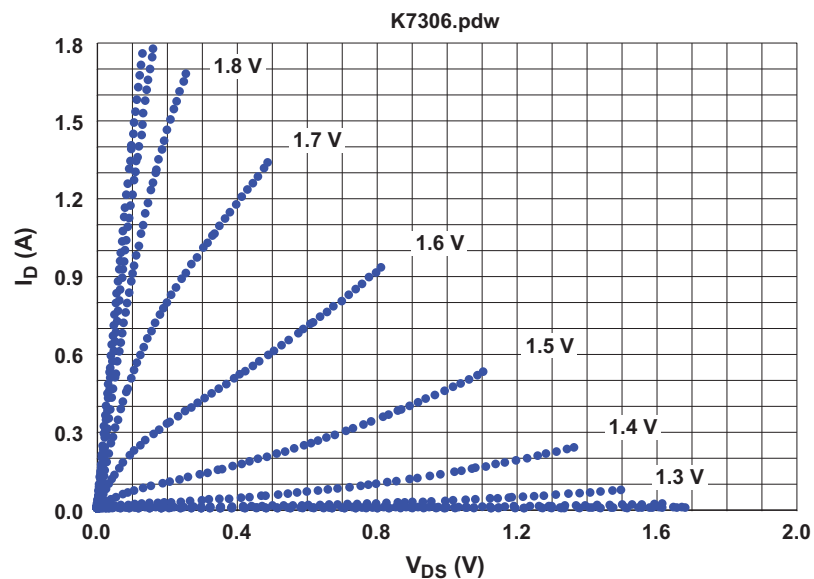
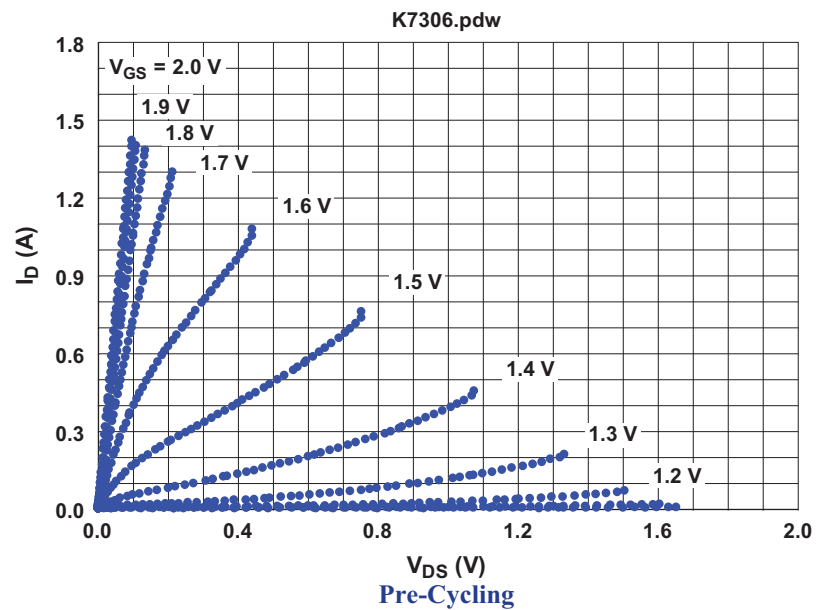
After 500 Cycles



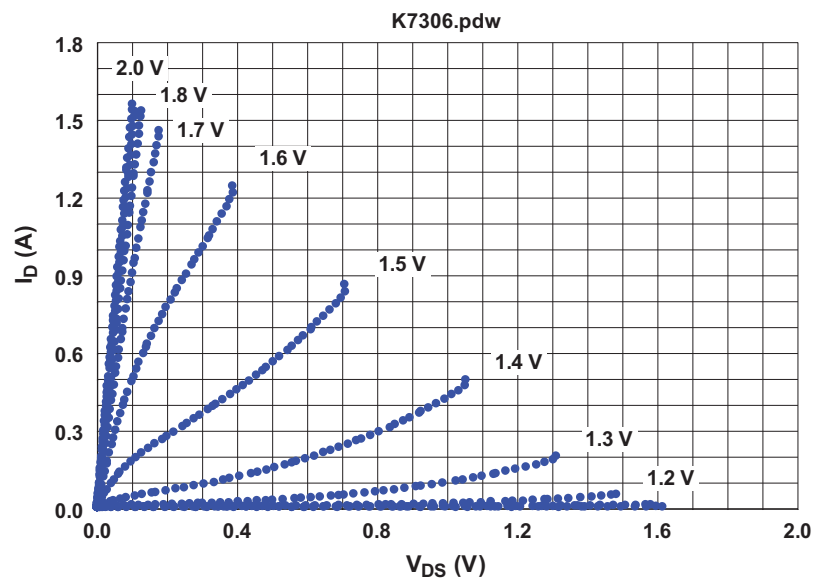
After 1000 Cycles



I-V Curves for K7306 (control EPC2015)



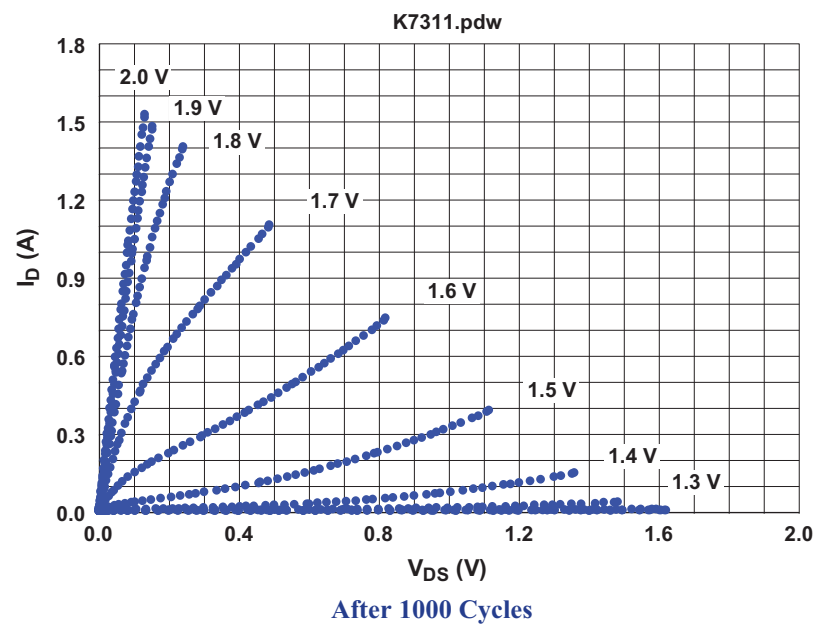
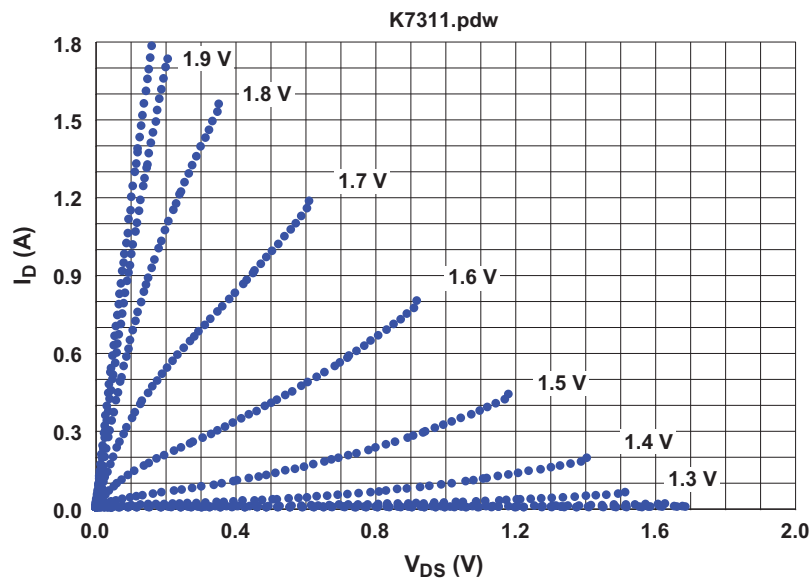
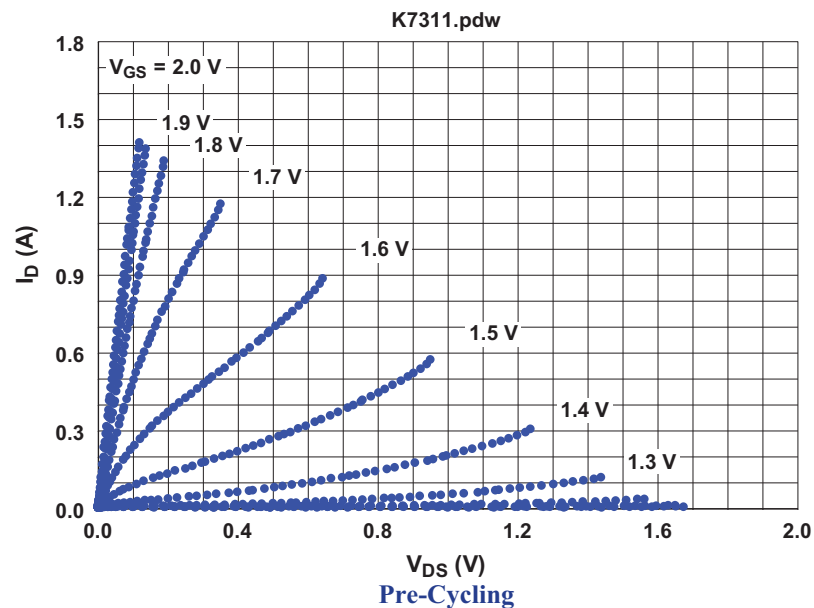
After 500 Cycles



After 1000 Cycles

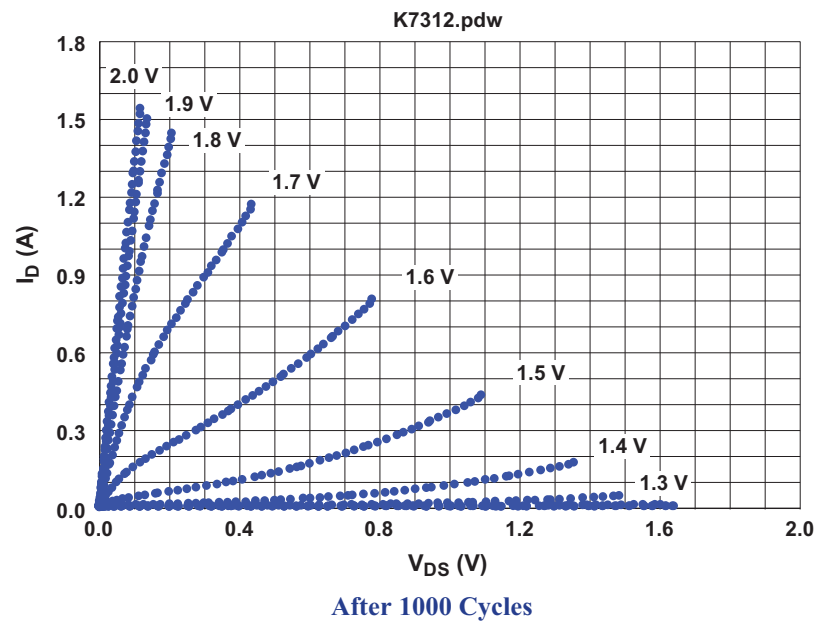
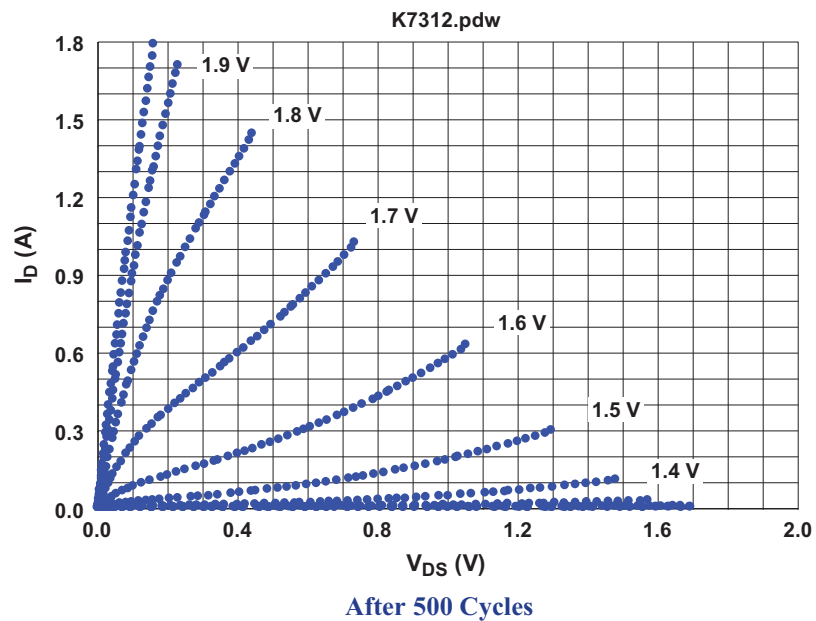
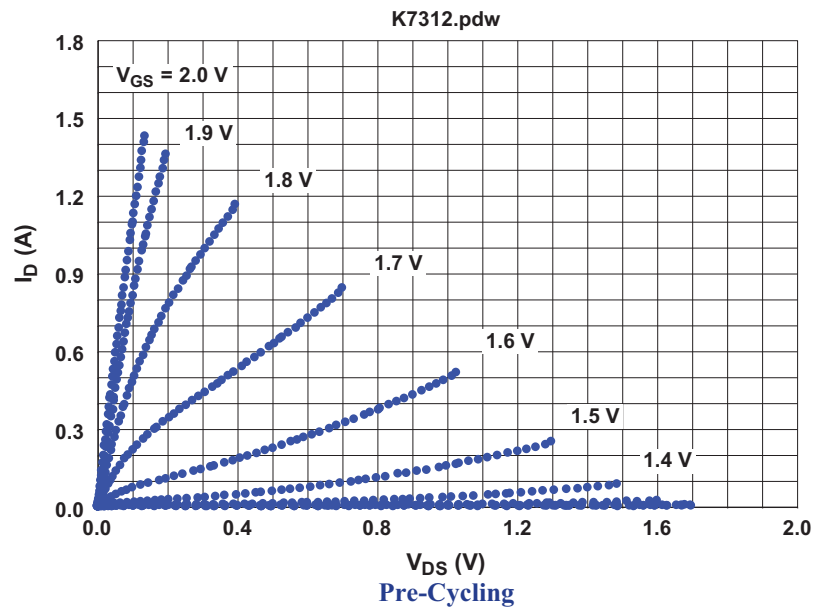


I-V Curves for K7311 (control EPC2015)



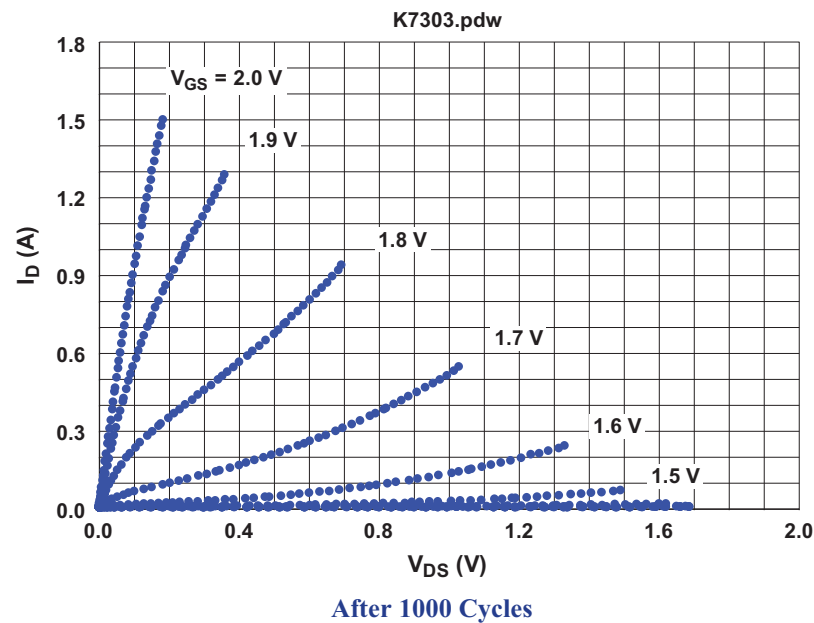
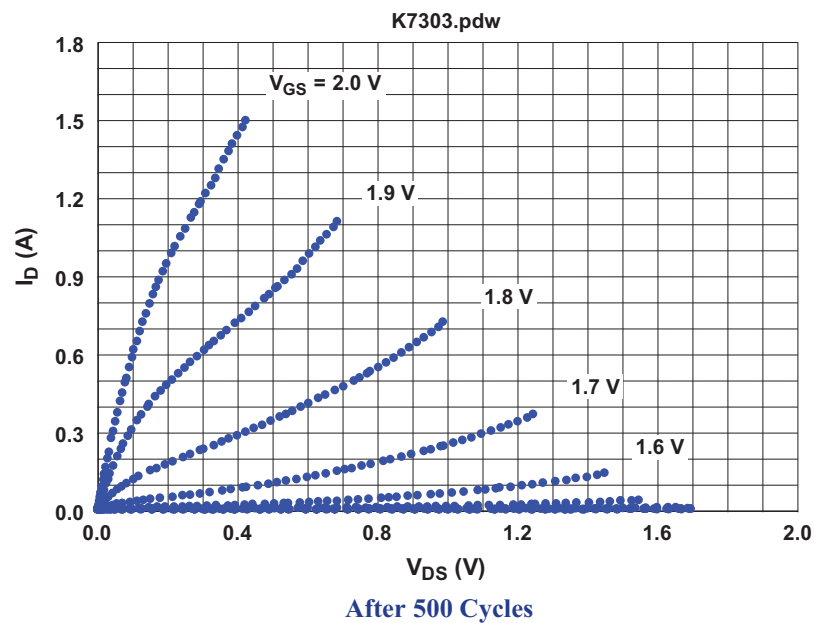
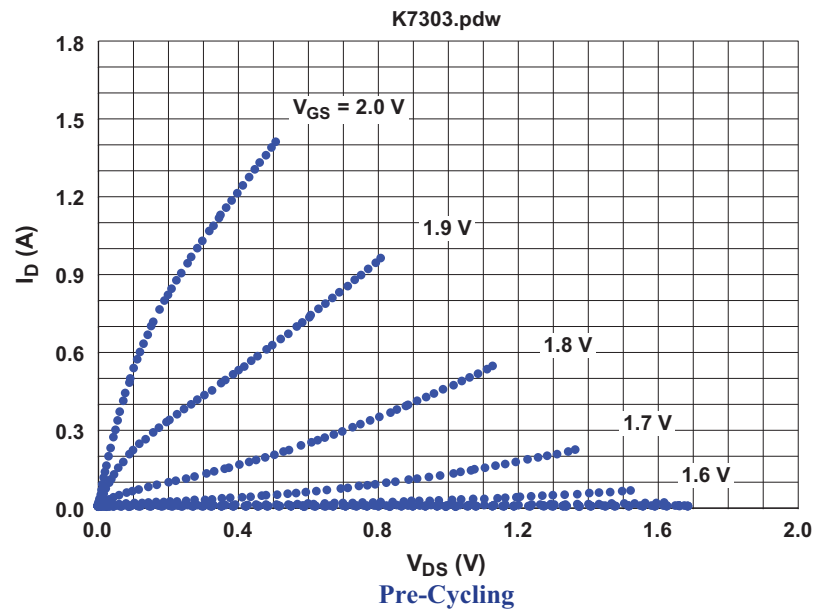


I-V Curves for K7312 (control EPC2015)



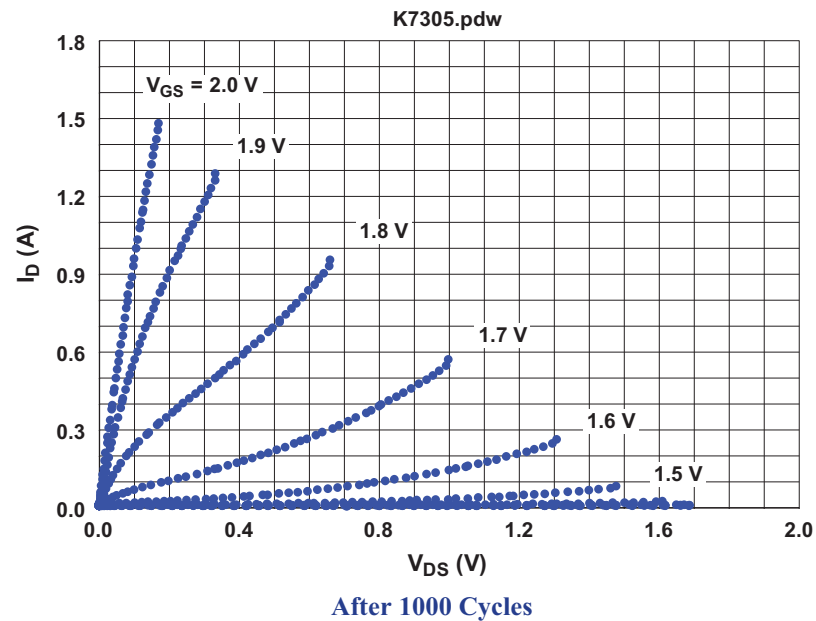
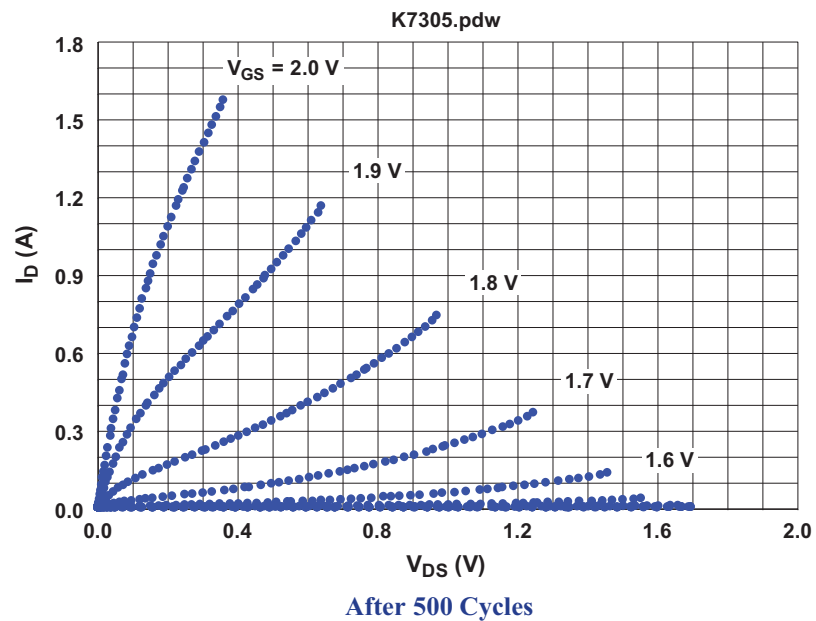
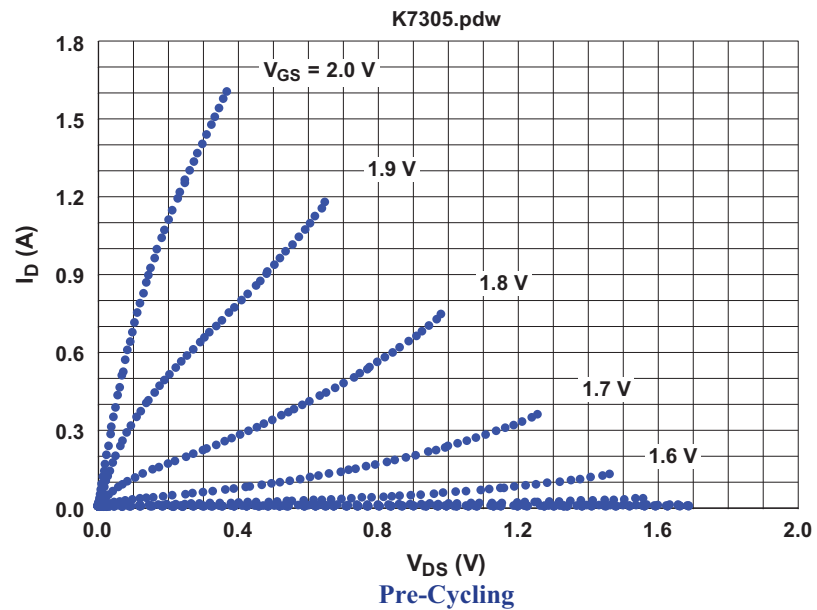


I-V Curves for K7303 (irradiated EPC2015)





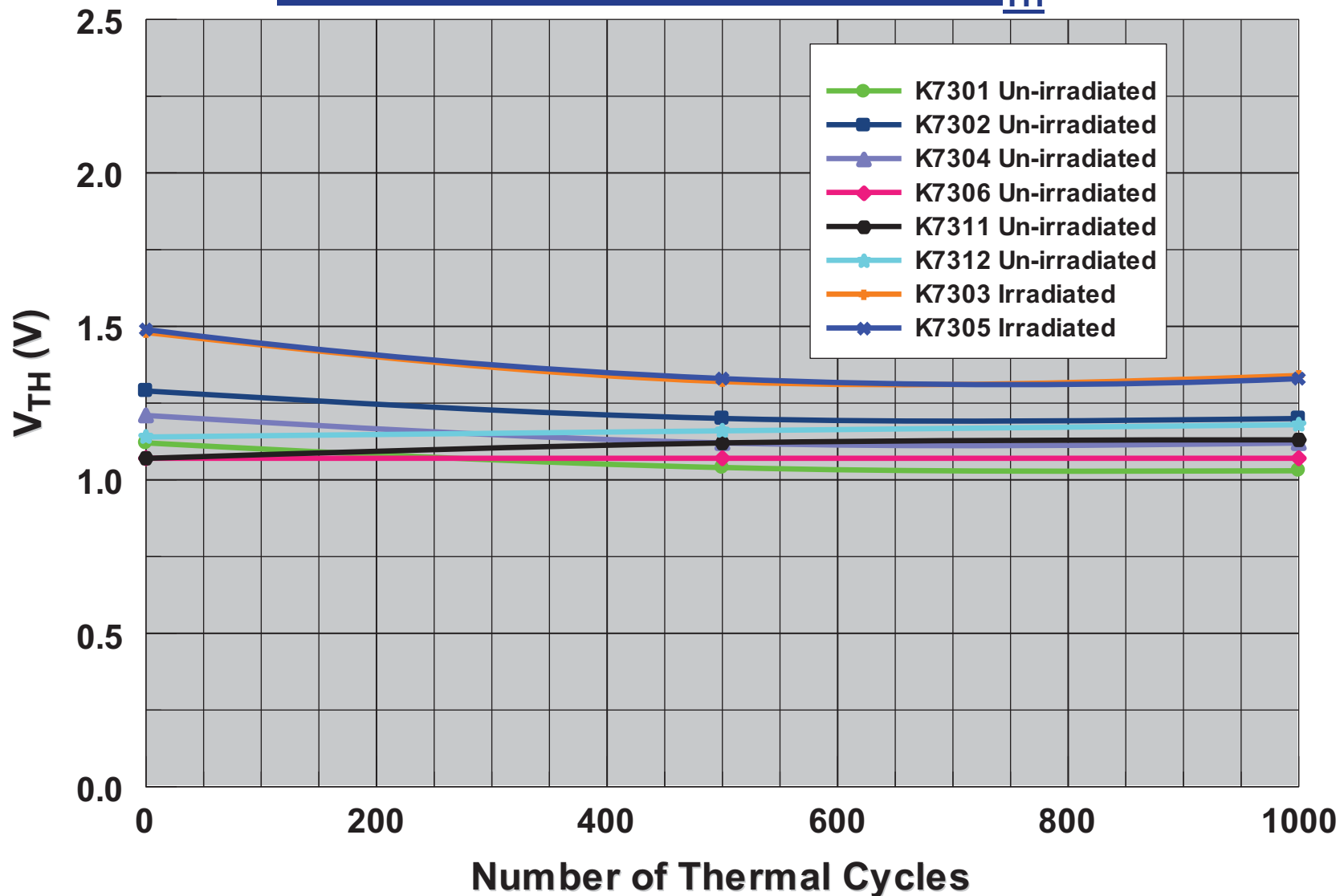
I-V Curves for K7305 (irradiated EPC2015)

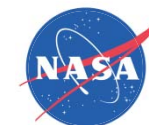




EPC2105

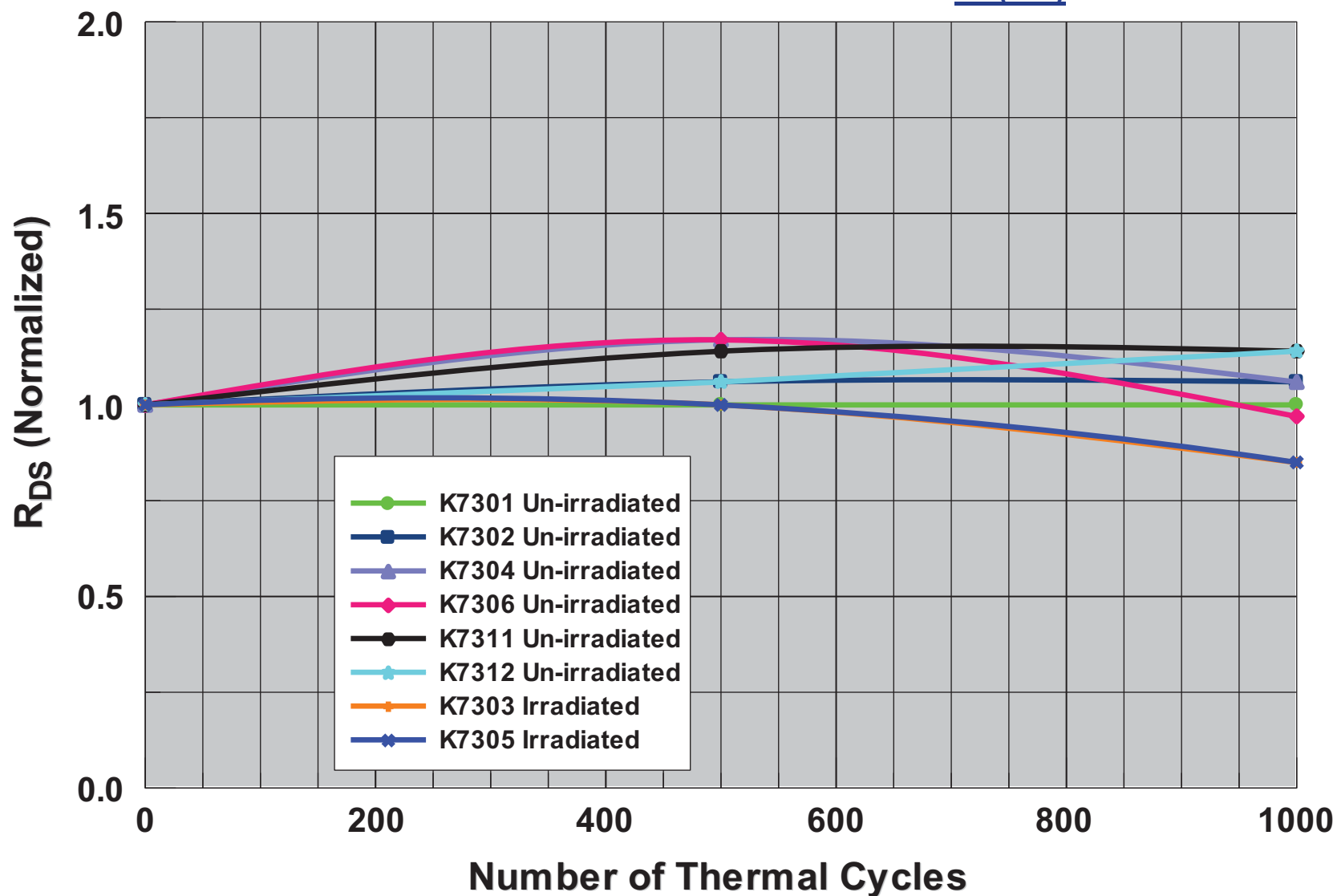
GATE THRESHOLD VOLTAGE, V_{TH}





EPC2015

Drain-Source On Resistance, $R_{DS(ON)}$





OBSERVATIONS

- All eight EPC2015 GaN transistors, control & irradiated, remained functional after exposure to radiation followed by 1000 thermal cycles between -55 & +125 °C
- Irradiated devices had a higher $R_{DS(ON)}$ and a higher V_{TH}
- Insignificant changes in the I-V characteristics of control samples due to cycling
- Thermal cycling seemed to cause a slight reduction in the $R_{DS(ON)}$ and the V_{TH} of the irradiated parts
- No alteration in device packaging or terminations

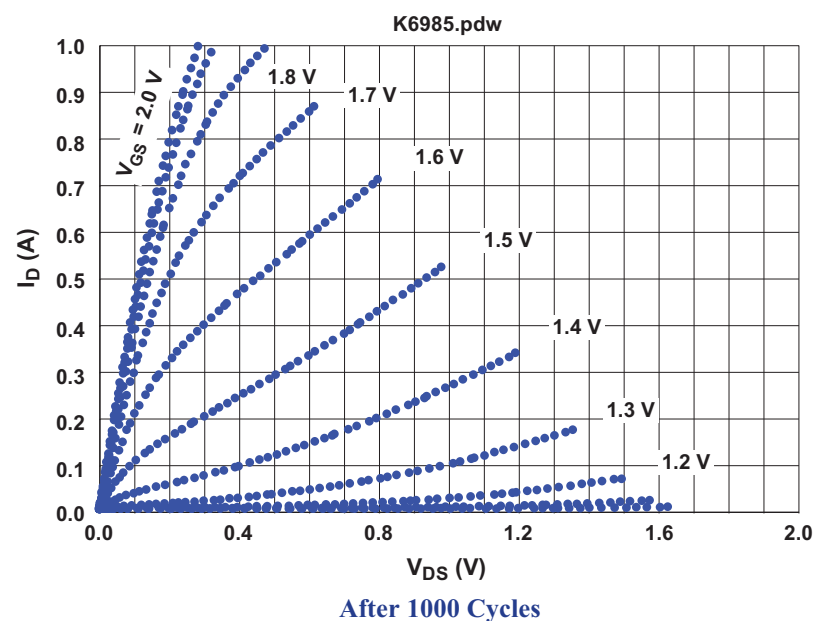
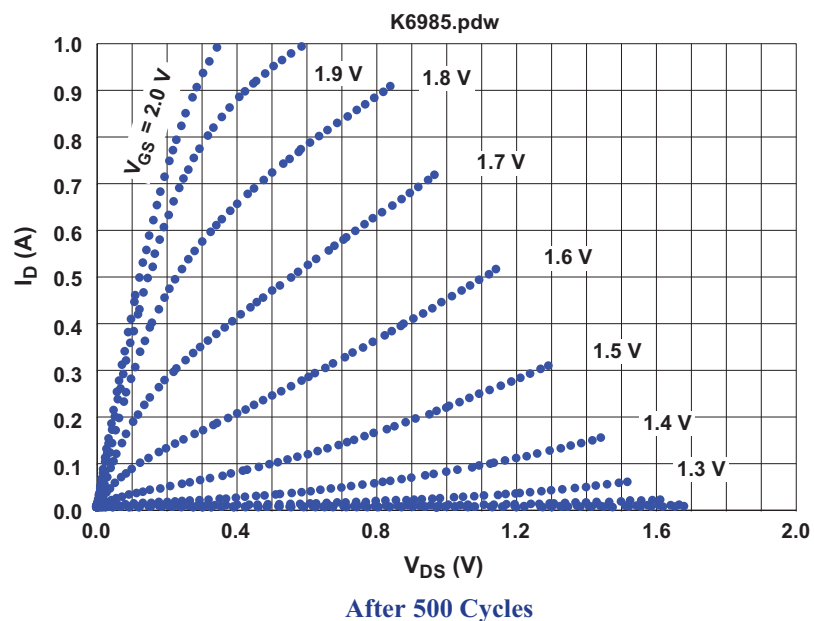
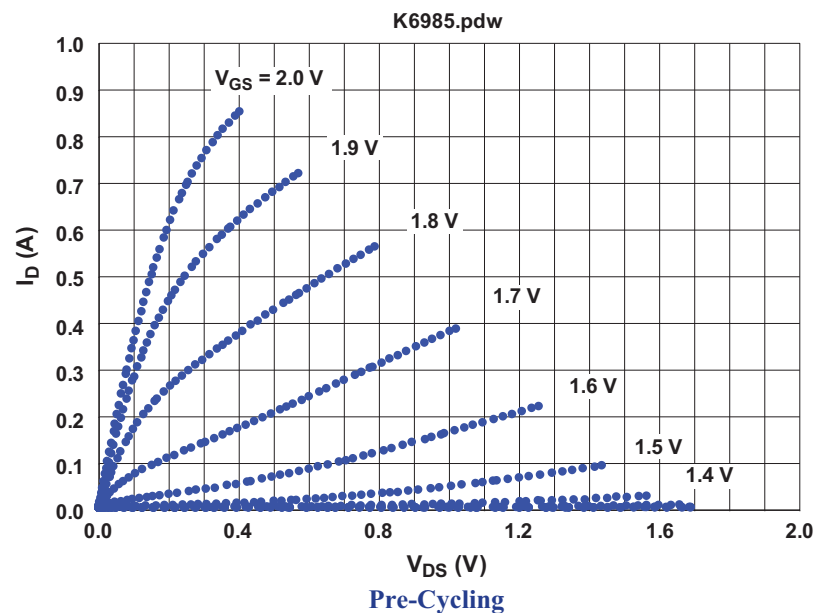


EPC2014 Enhancement Mode Power FET

EPC2014 40V, 10A, 16mΩ	
Control Parts	Irradiated Parts
K6985	K7325
K6986	K7328
K7333	K7347
K7336	
K7346	
K7072	

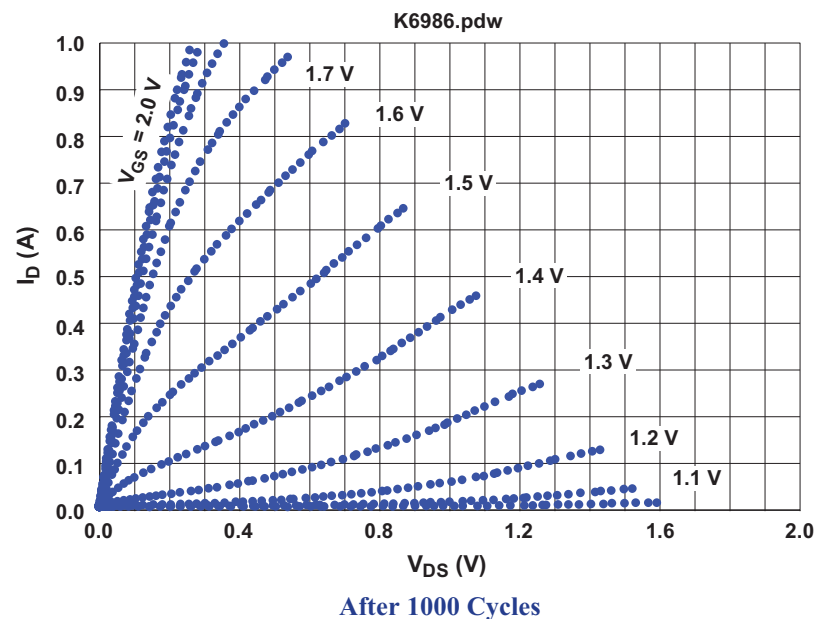
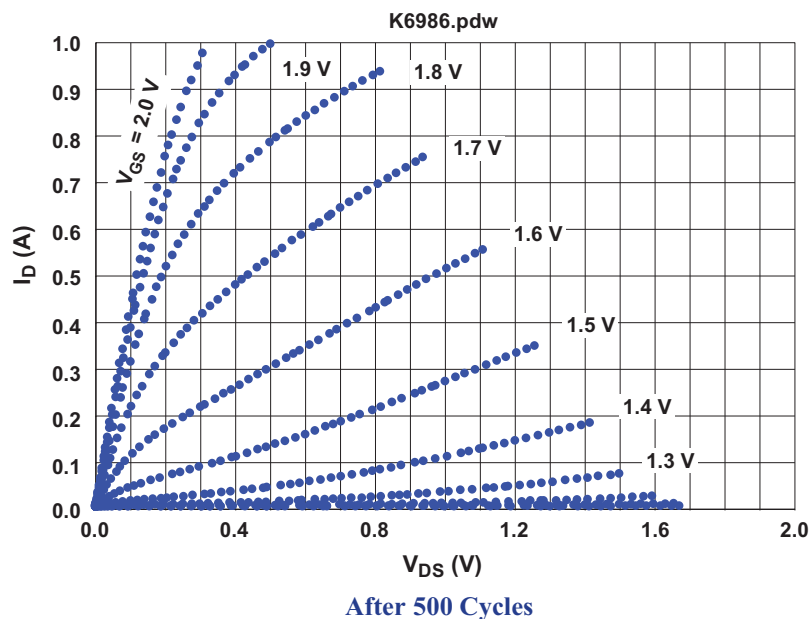
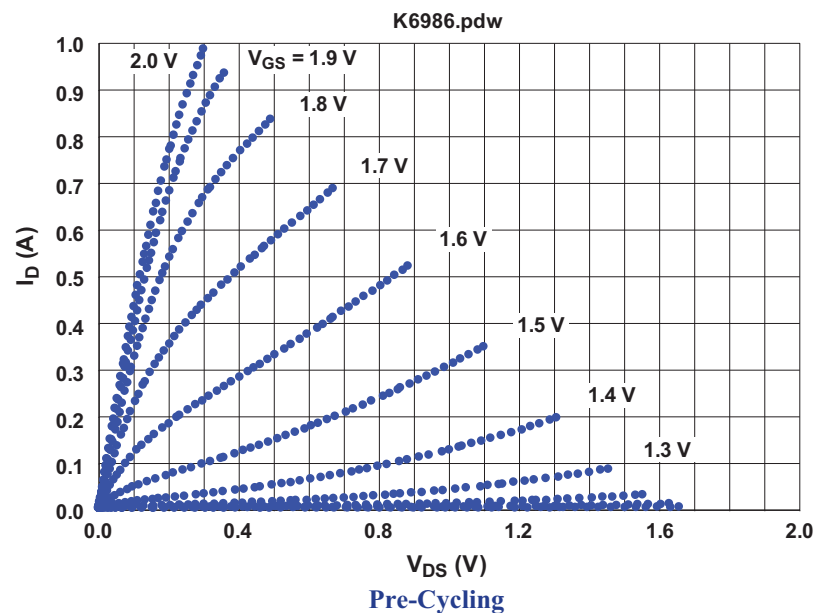


I-V Curves for K6985 (control EPC2014)



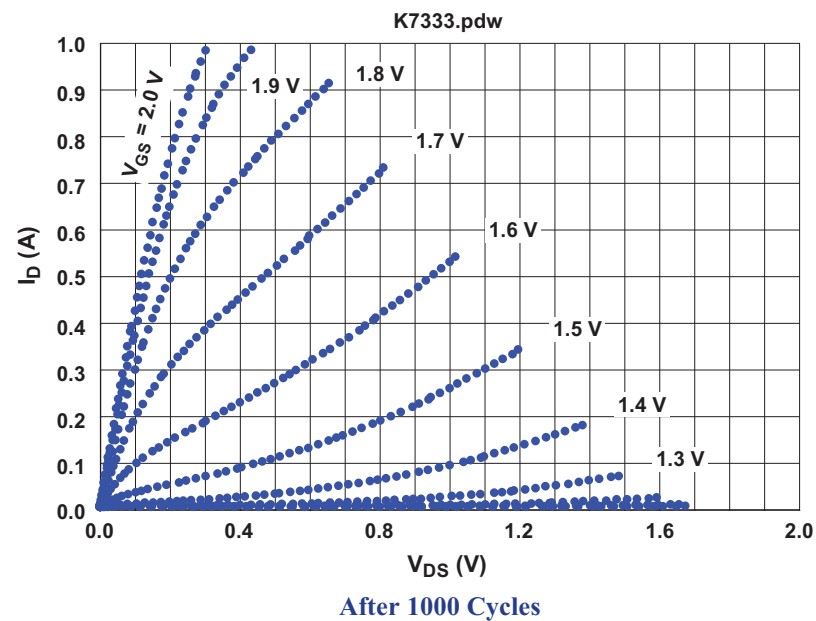
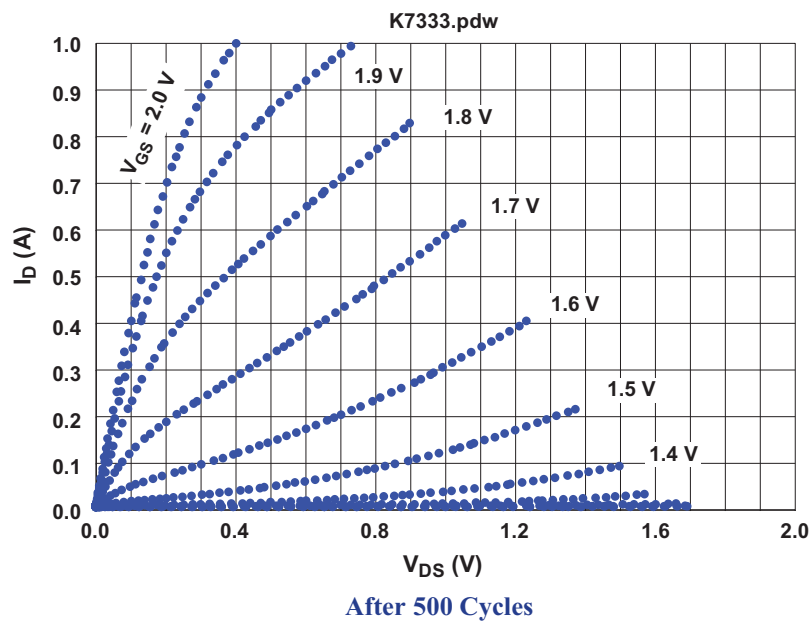
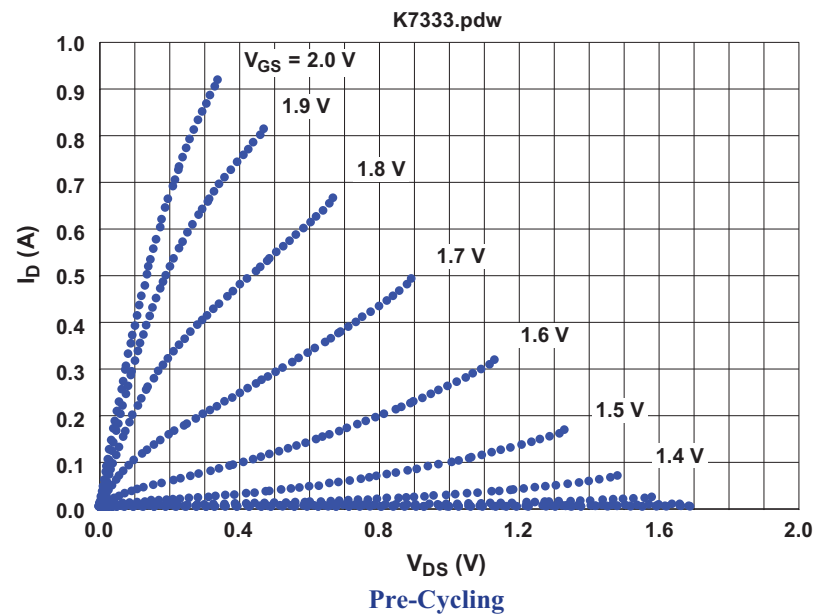


I-V Curves for K6986 (control EPC2014)



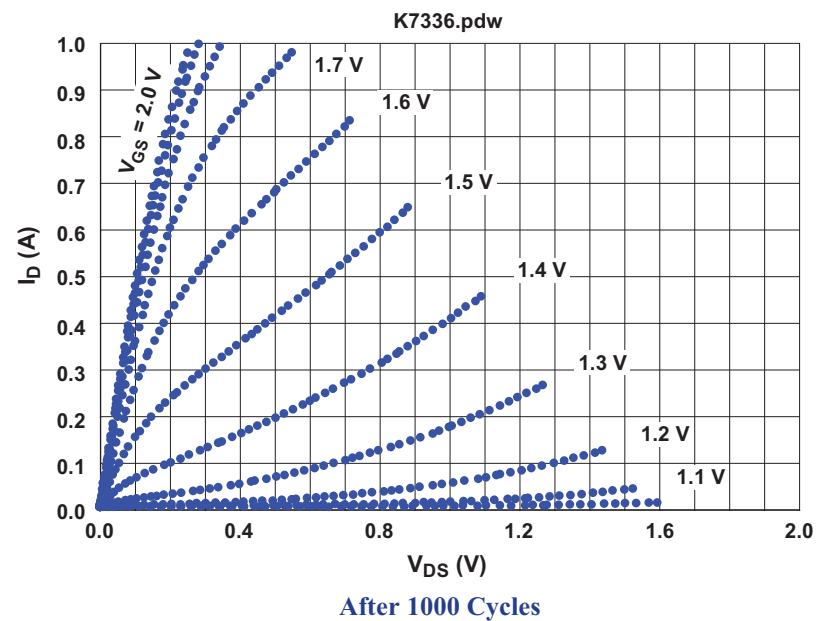
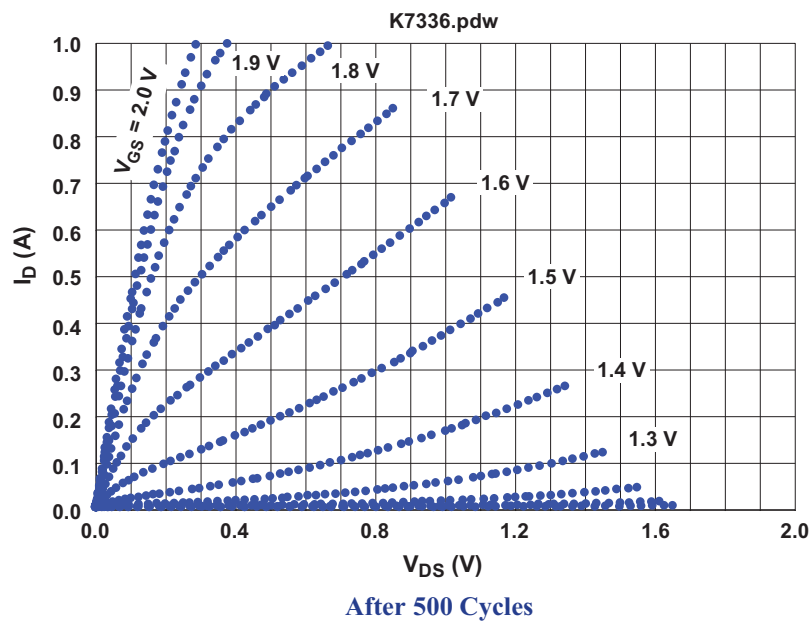
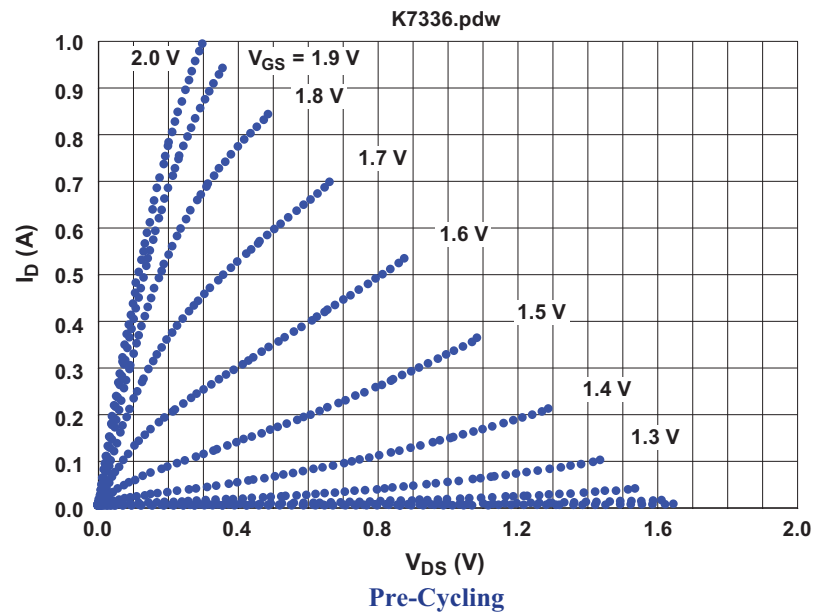


I-V Curves for K7333 (control EPC2014)



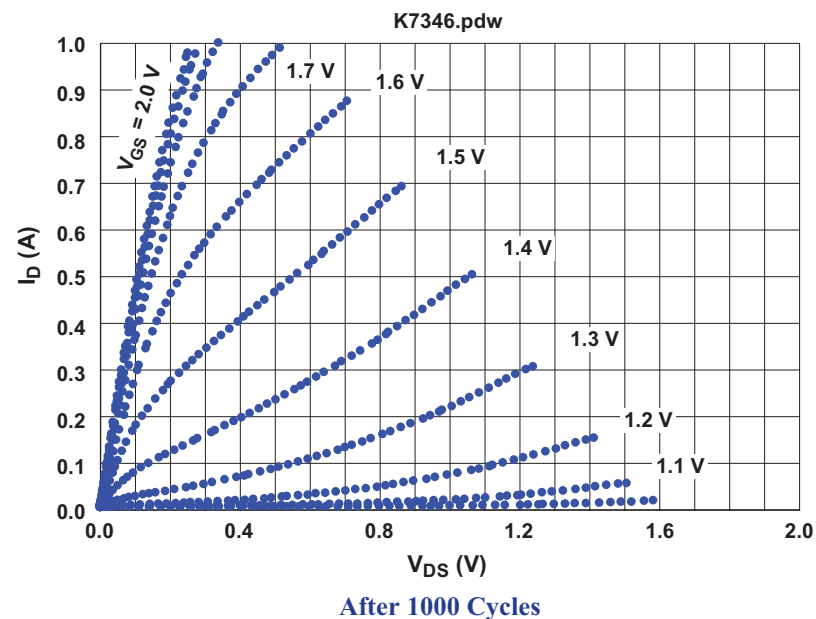
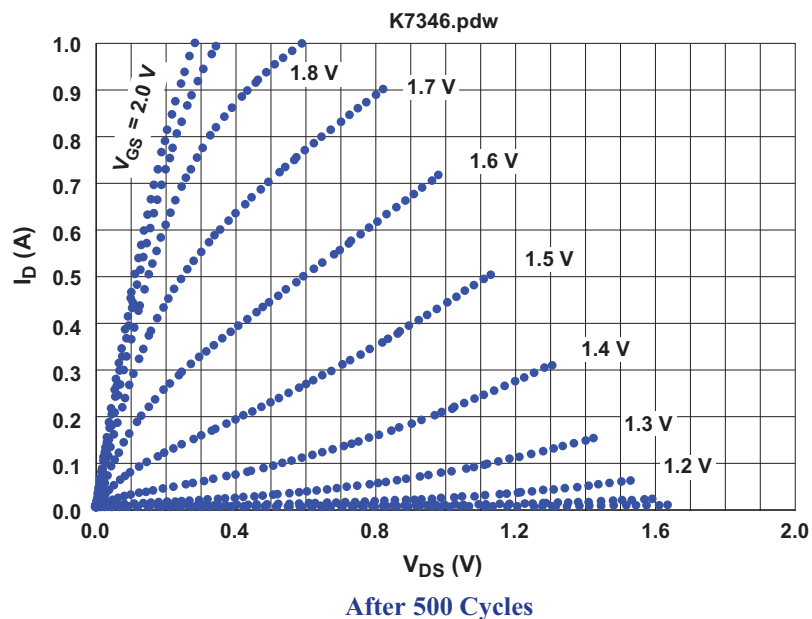
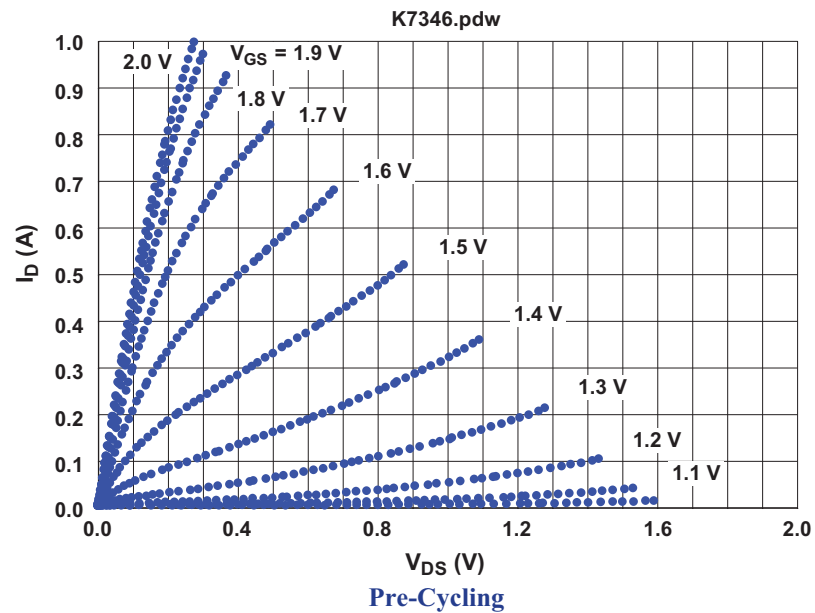


I-V Curves for K7336 (control EPC2014)



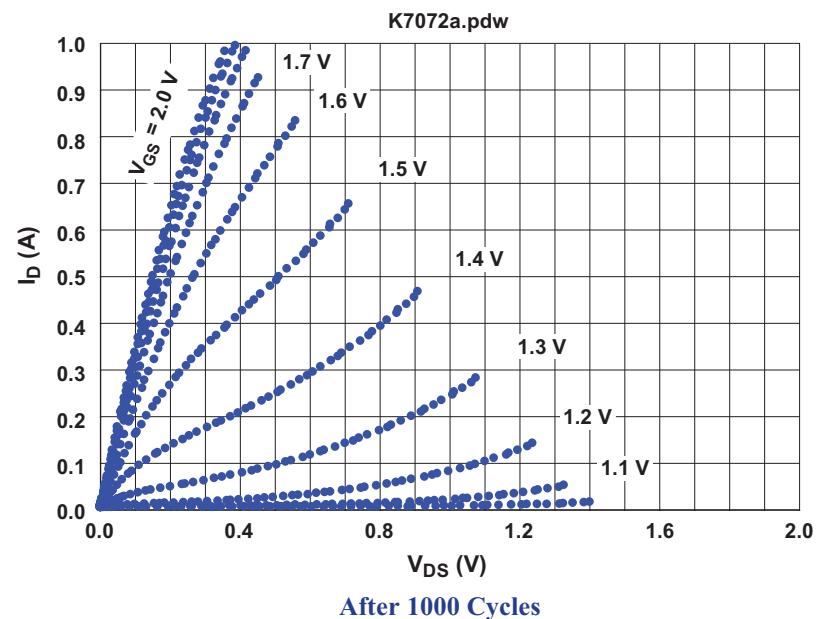
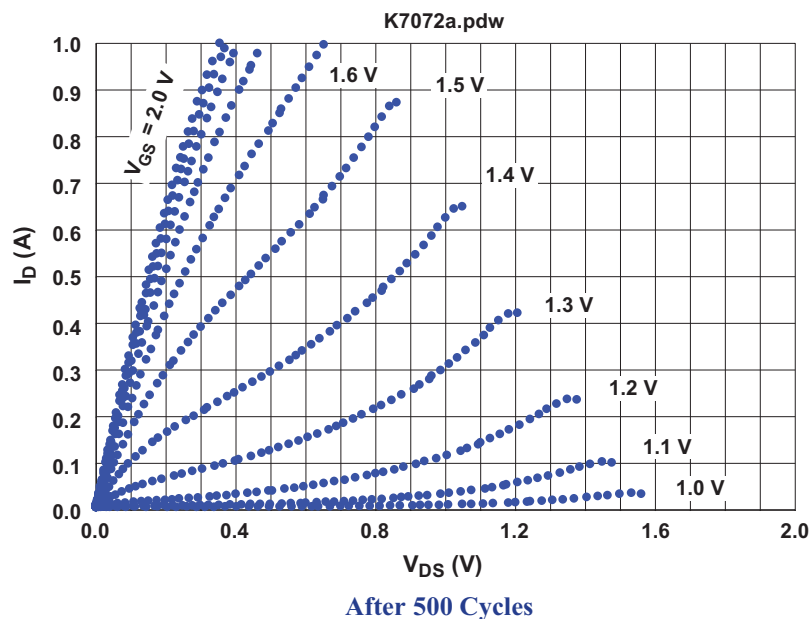
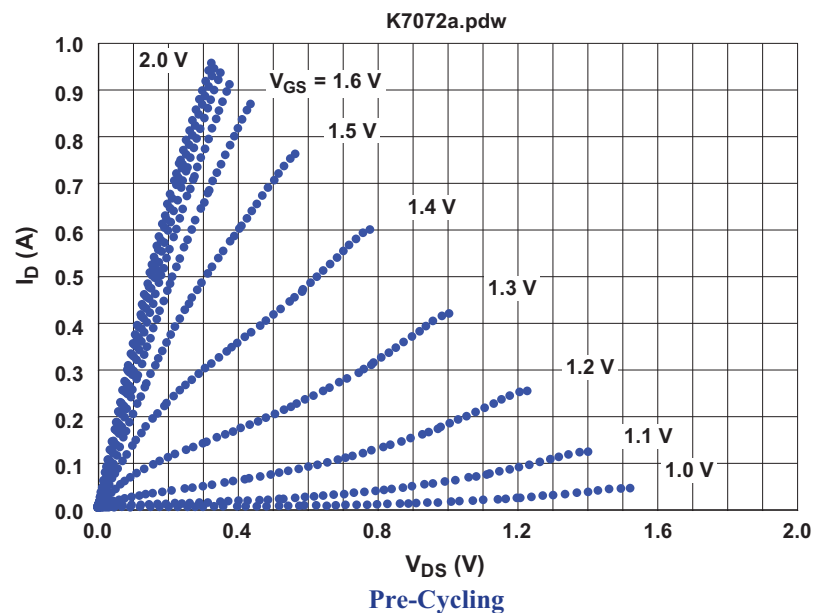


I-V Curves for K7346 (control EPC2104)



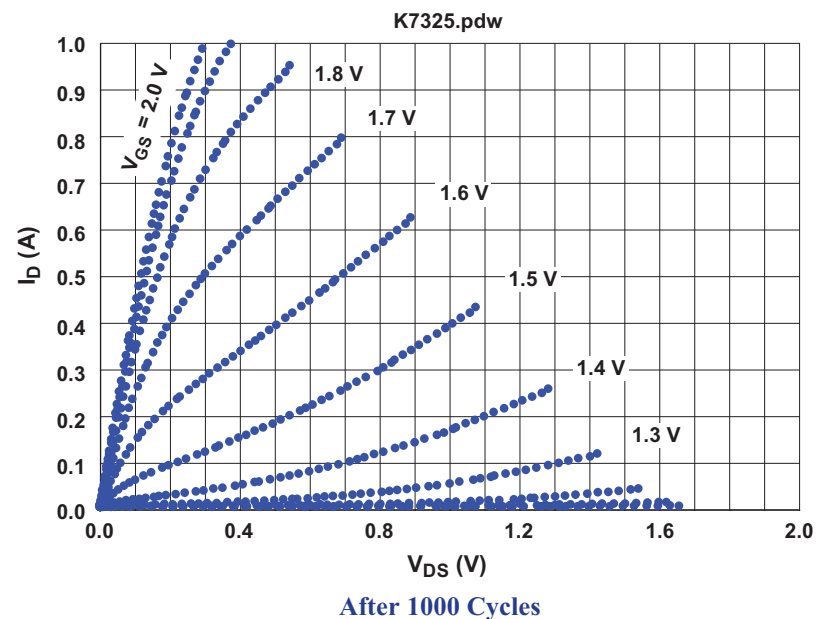
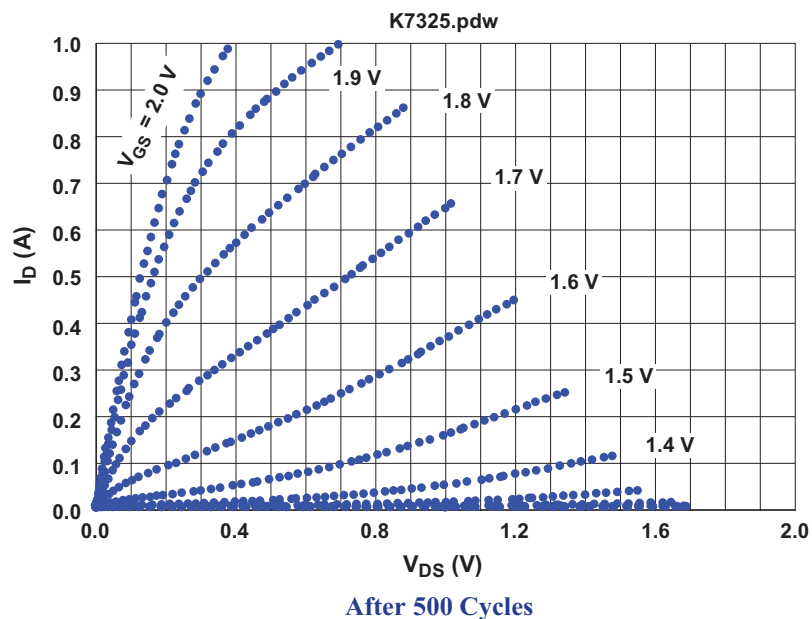
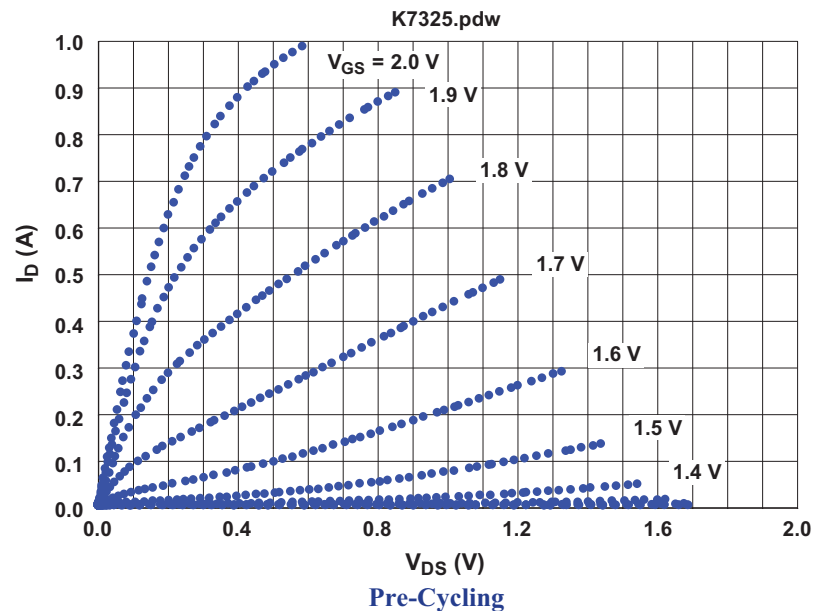


I-V Curves for K7072 (control EPC2014)



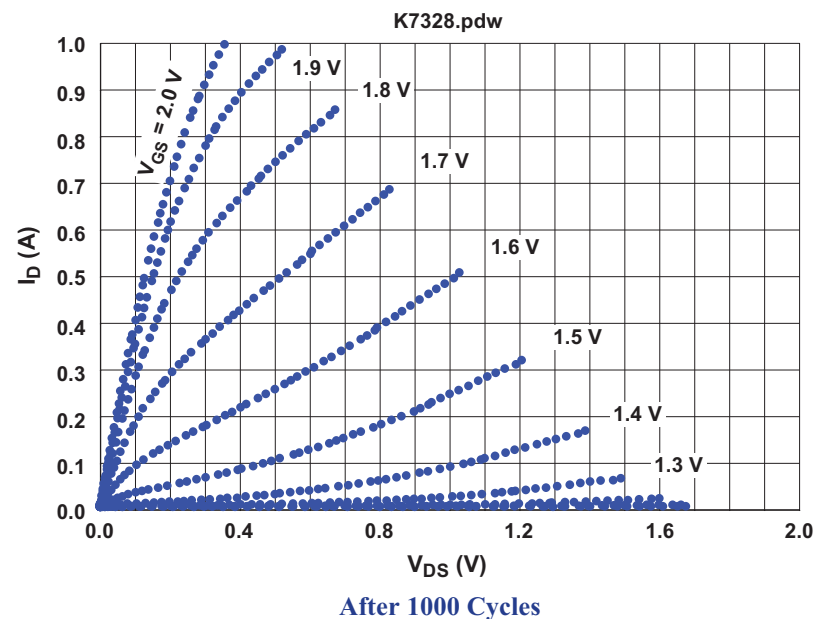
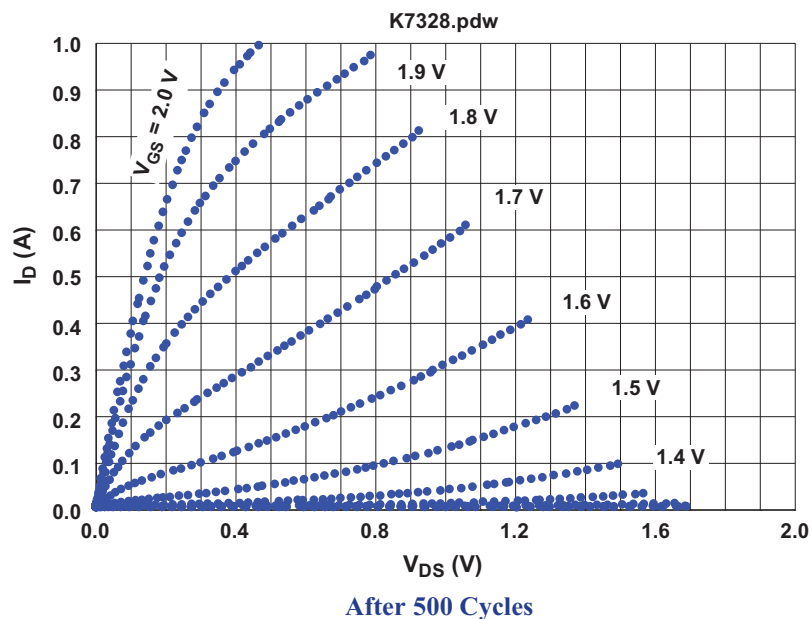
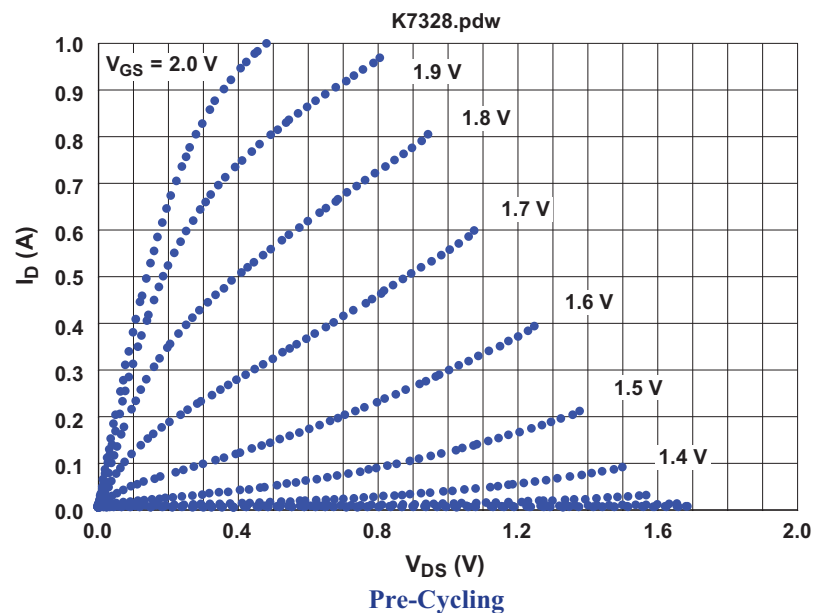


I-V Curves for K7325 (irradiated EPC2014)



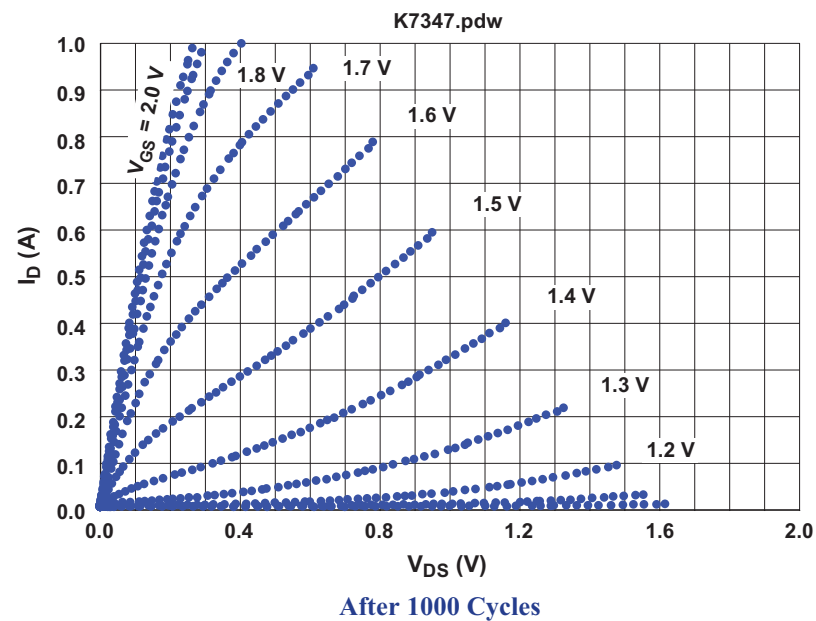
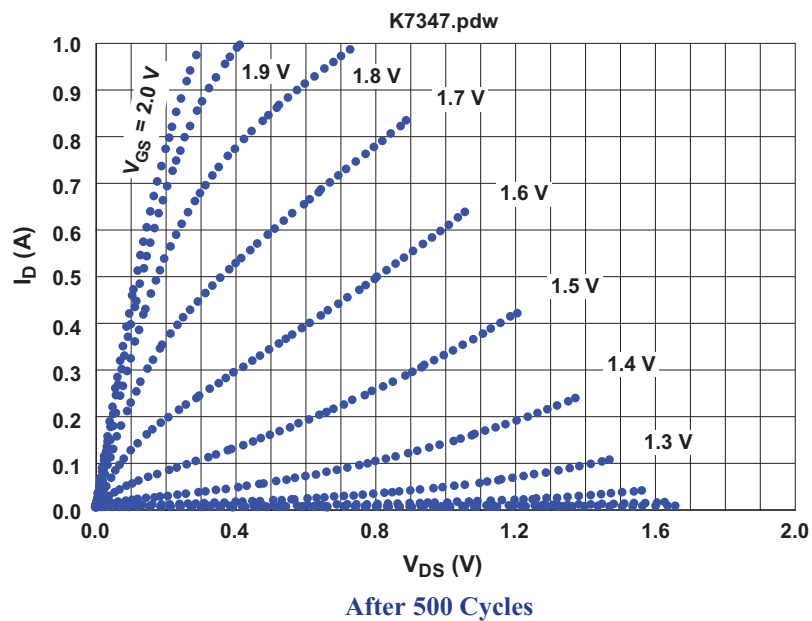
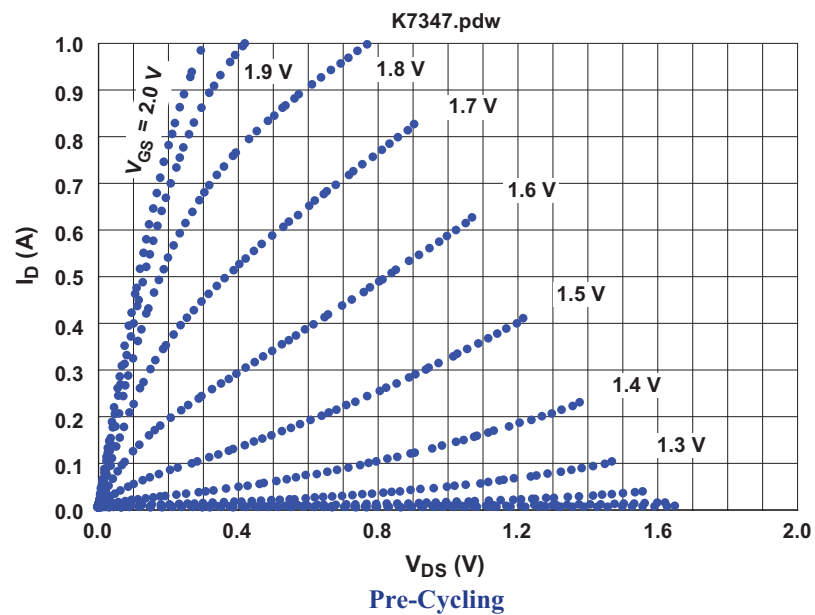


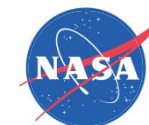
I-V Curves for K7328 (irradiated EPC2014)





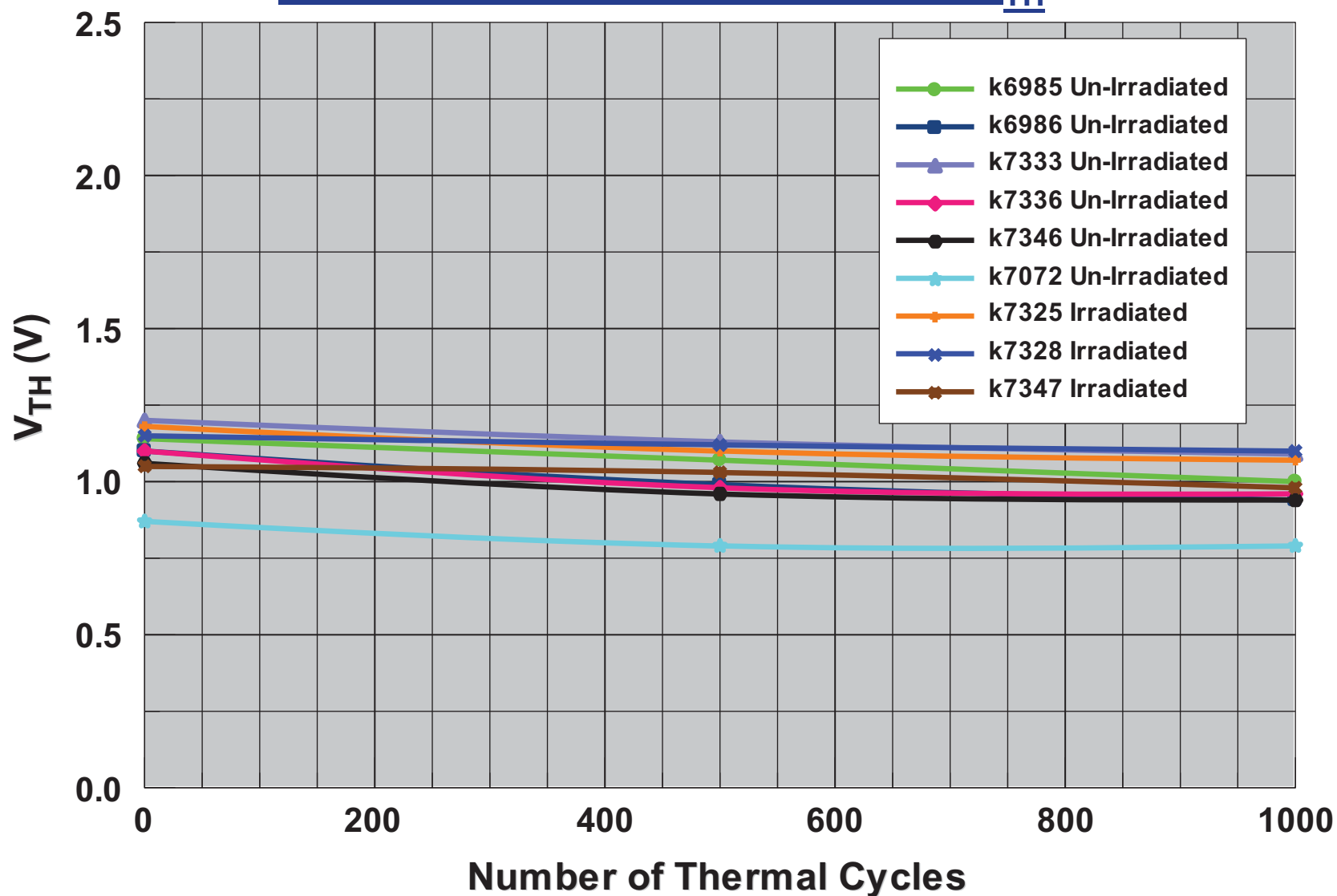
I-V Curves for K7347 (irradiated EPC2014)





EPC2014

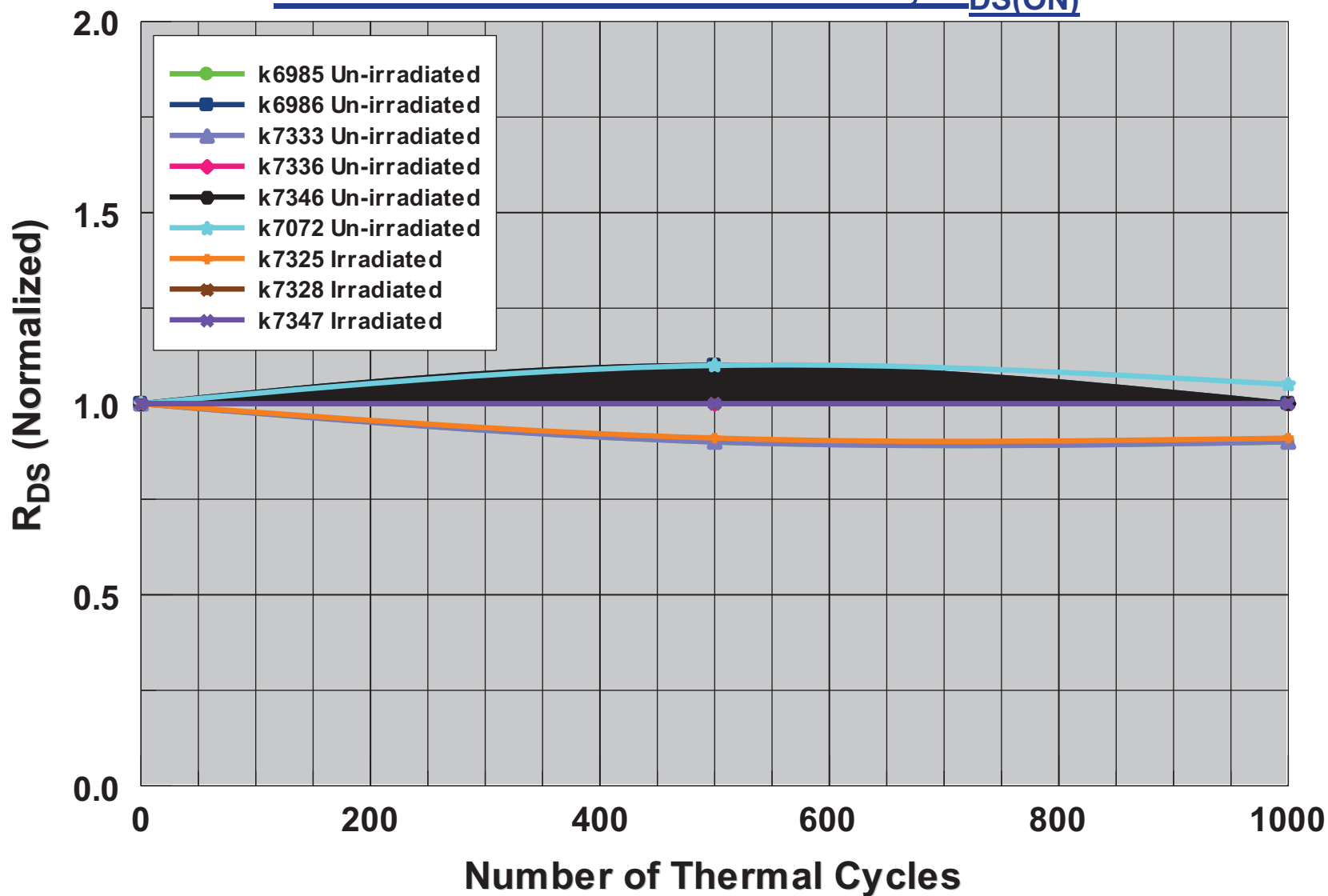
GATE THRESHOLD VOLTAGE, V_{TH}





EPC2014

Drain-Source On Resistance, $R_{DS(ON)}$





OBSERVATIONS

- All nine EPC2014 GaN transistors, control & irradiated, remained functional after exposure to radiation followed by 1000 thermal cycles between -55 & +125 °C
- Slight changes in I-V curves of irradiated parts
- Thermal cycling seemed to slightly improve the I-V characteristics of both control and irradiated samples
- Part-to-part variation in output characteristics
- No alteration in device packaging or terminations

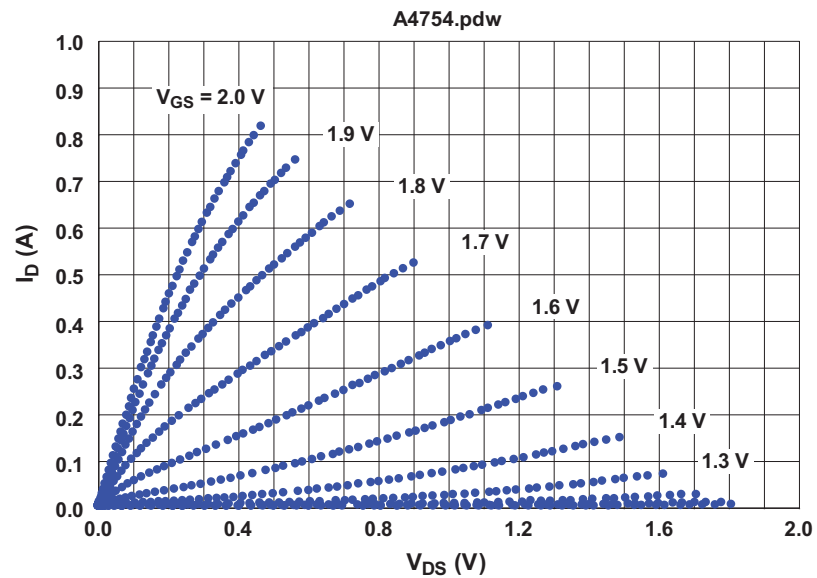


EPC2012 Enhancement Mode Power FET

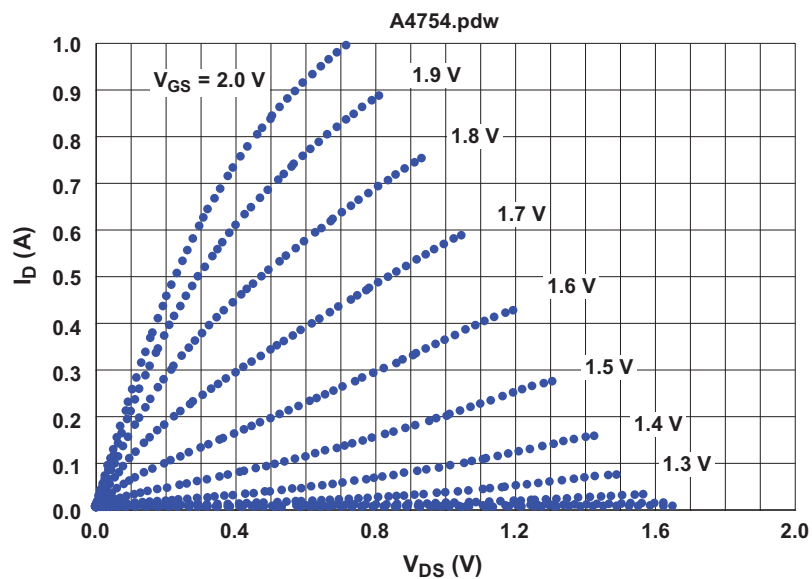
EPC2012 200V, 3A, 100mΩ	
Control Parts	Irradiated Parts
A4754	K7348
A4755	K7353
A4756	K7354
A4757	K7359
A4758	K7370
A4759	K7395
	K7396
	K7399
	K7364



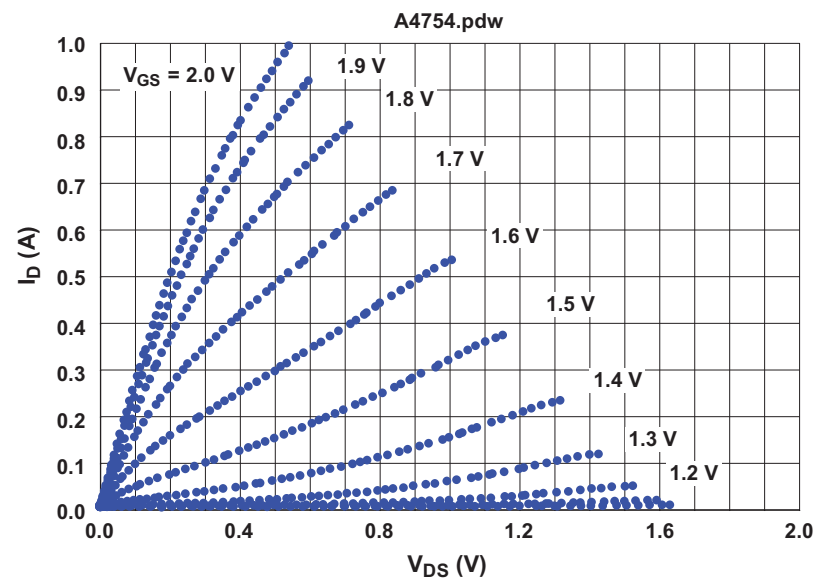
I-V Curves for A4754 (control EPC2012)



Pre-Cycling



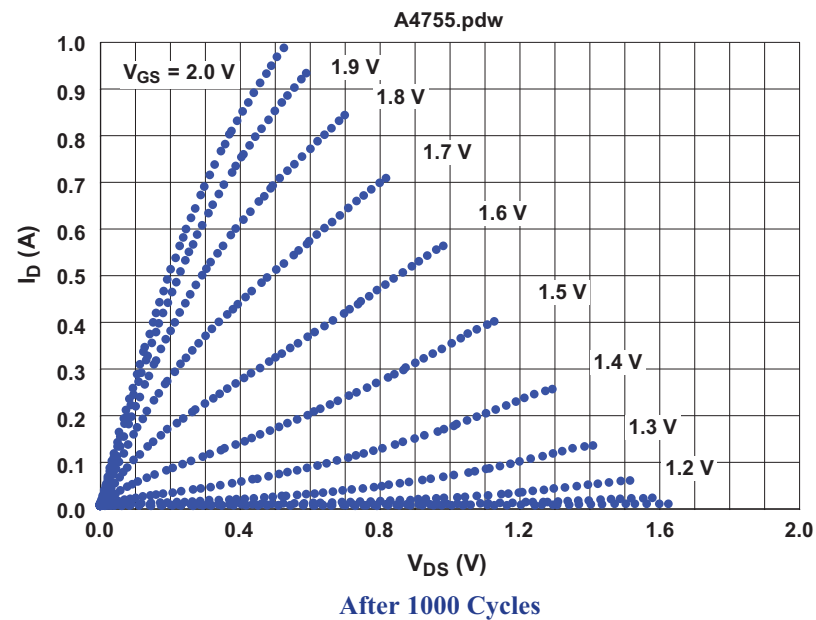
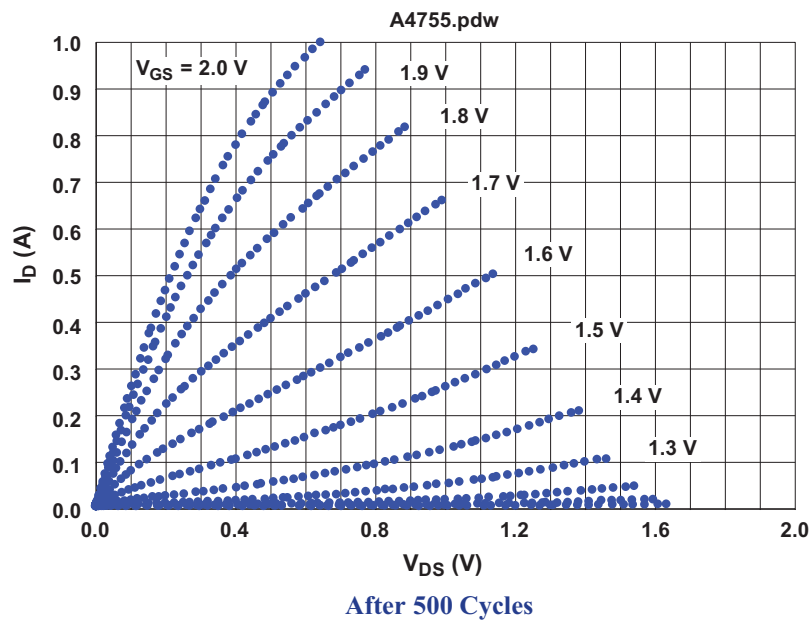
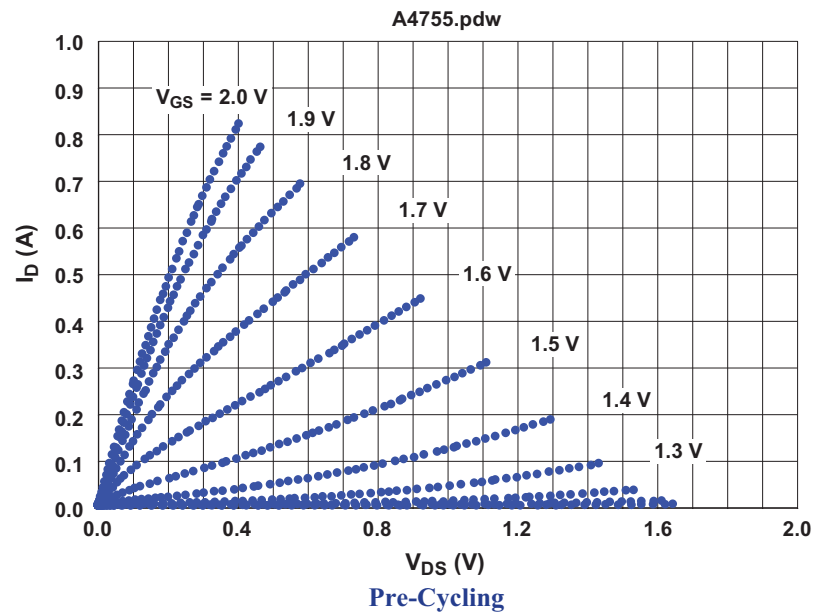
After 500 Cycles



After 1000 Cycles

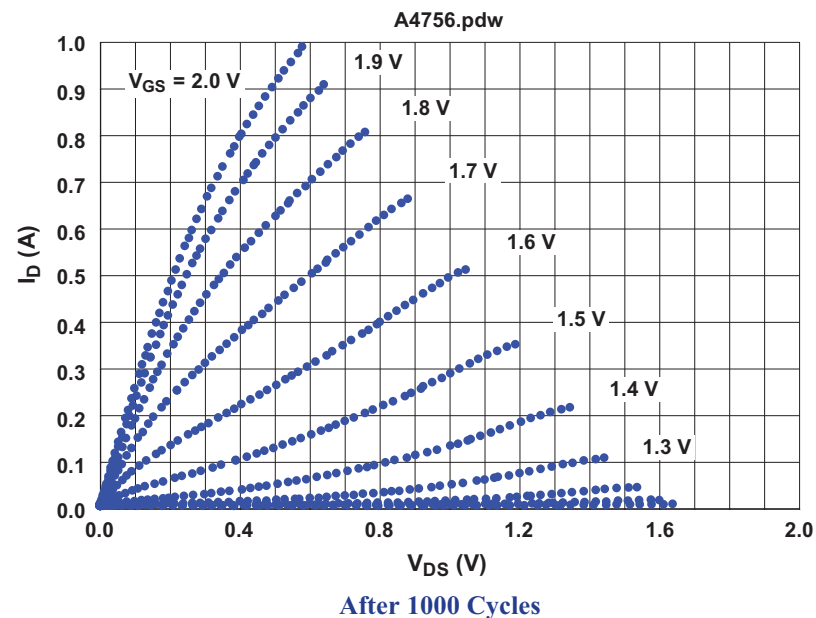
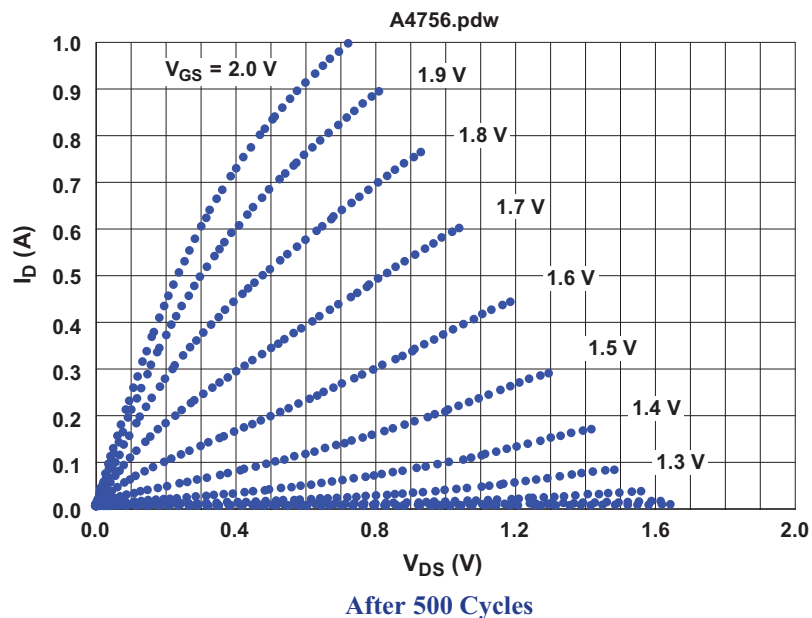
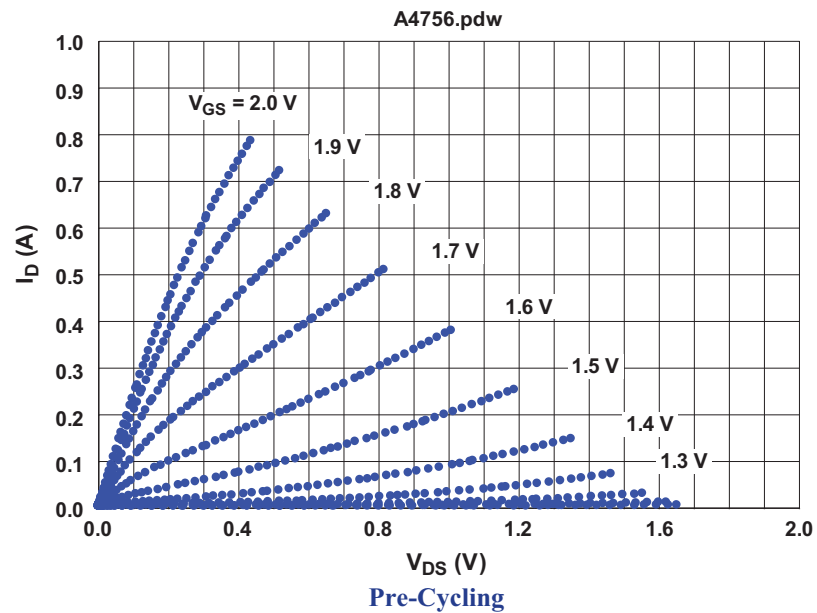


I-V Curves for A4755 (control EPC2012)



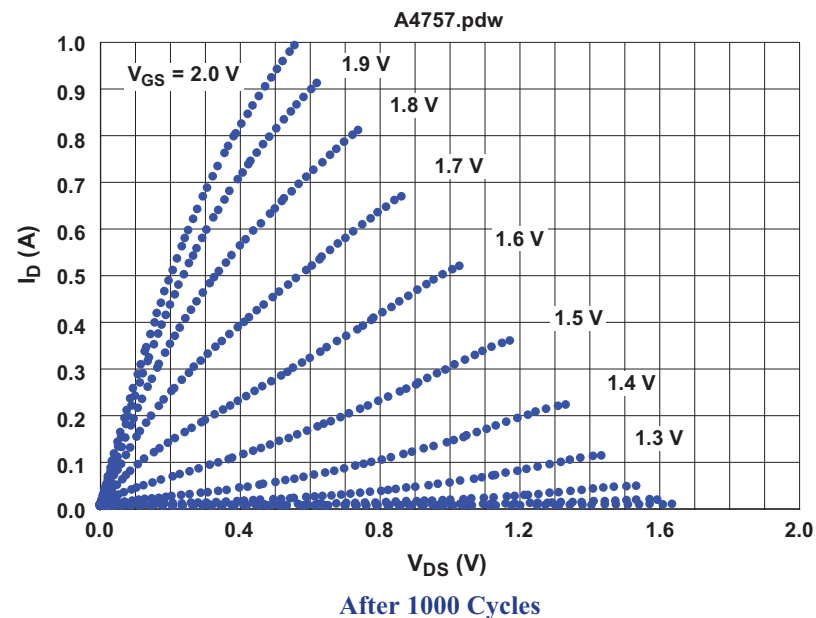
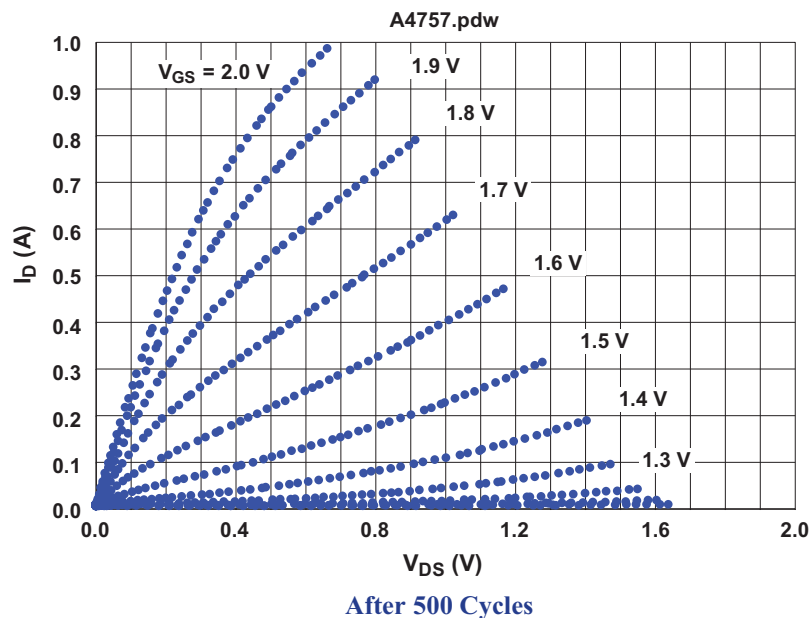
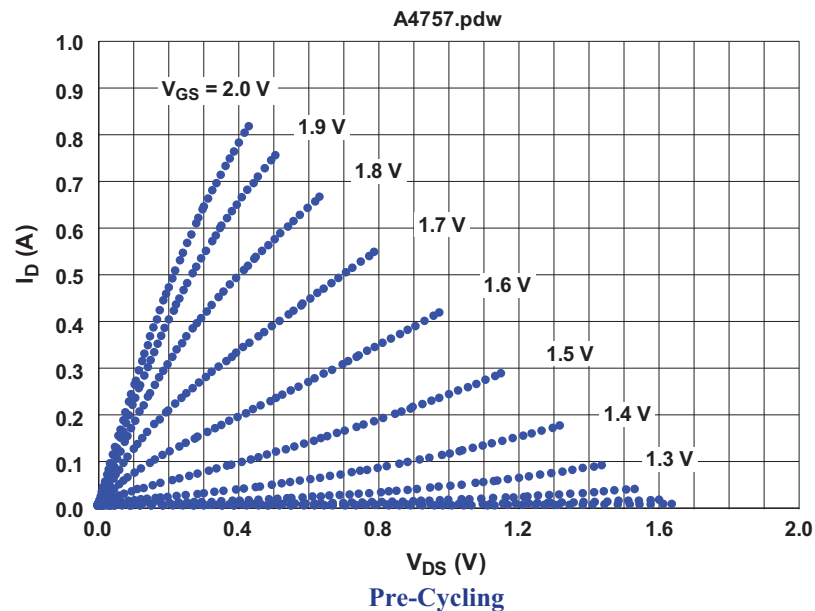


I-V Curves for A4756 (control EPC2012)



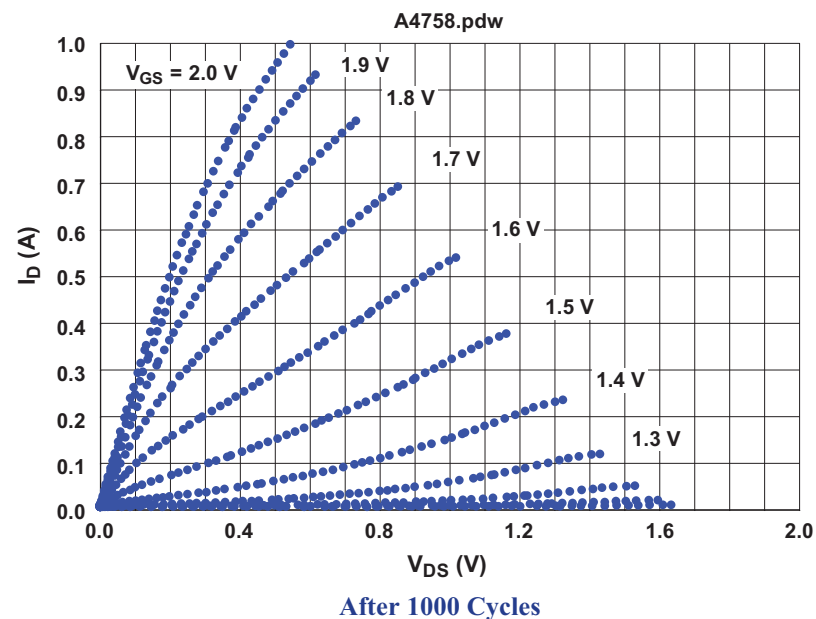
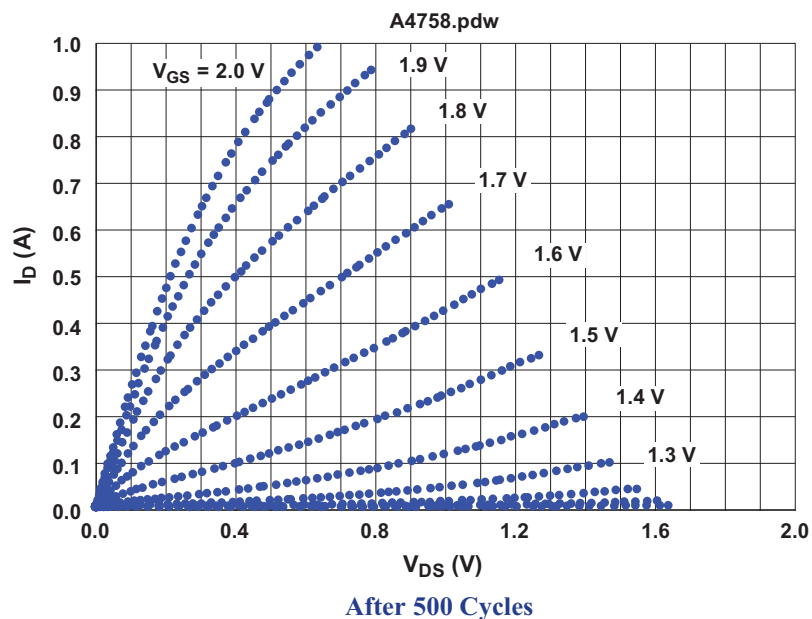
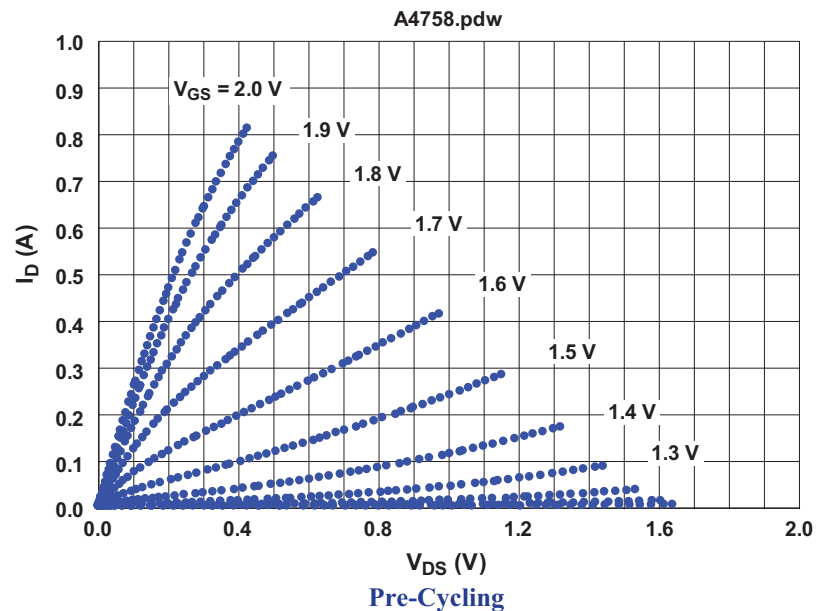


I-V Curves for A4757 (control EPC2012)



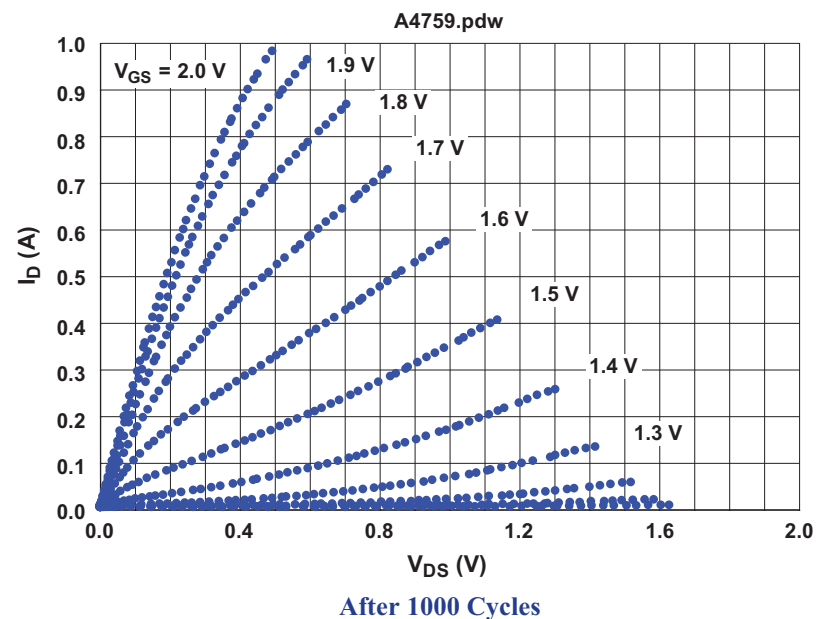
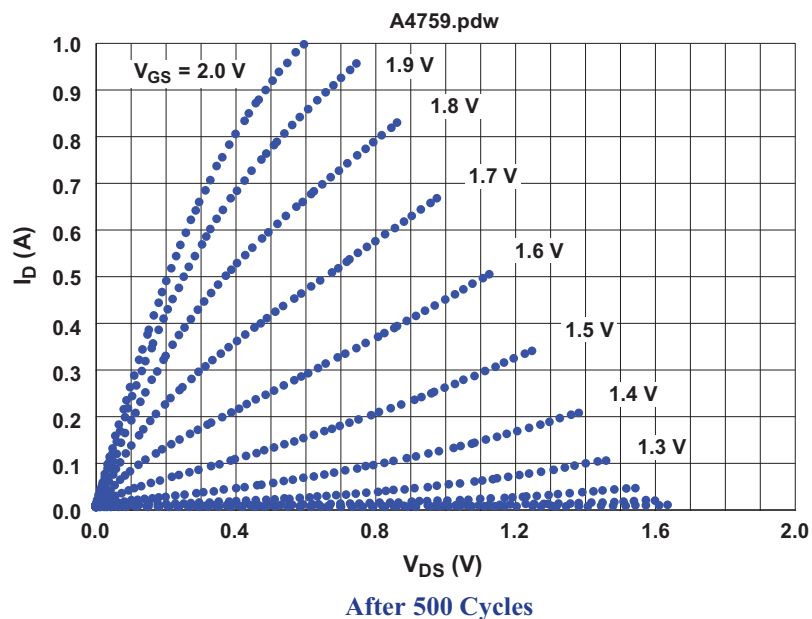
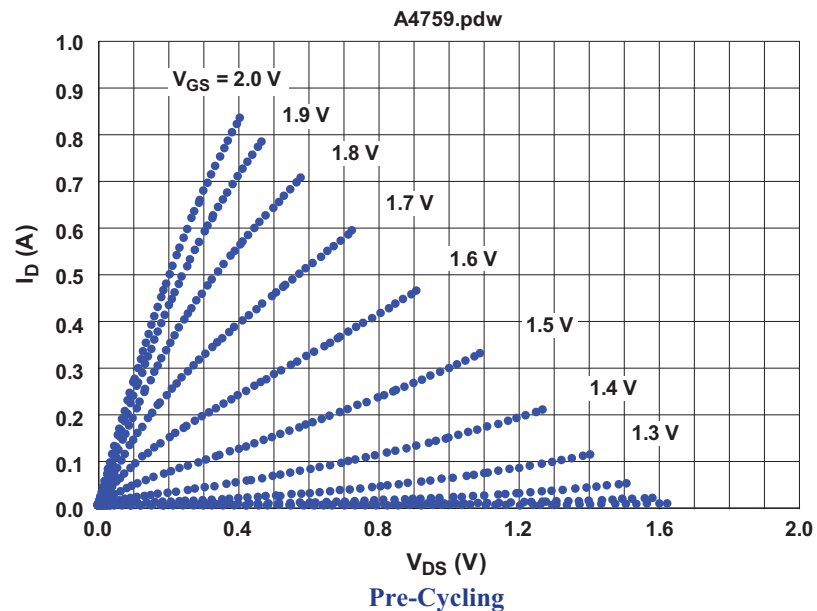


I-V Curves for A4758 (control EPC2012)



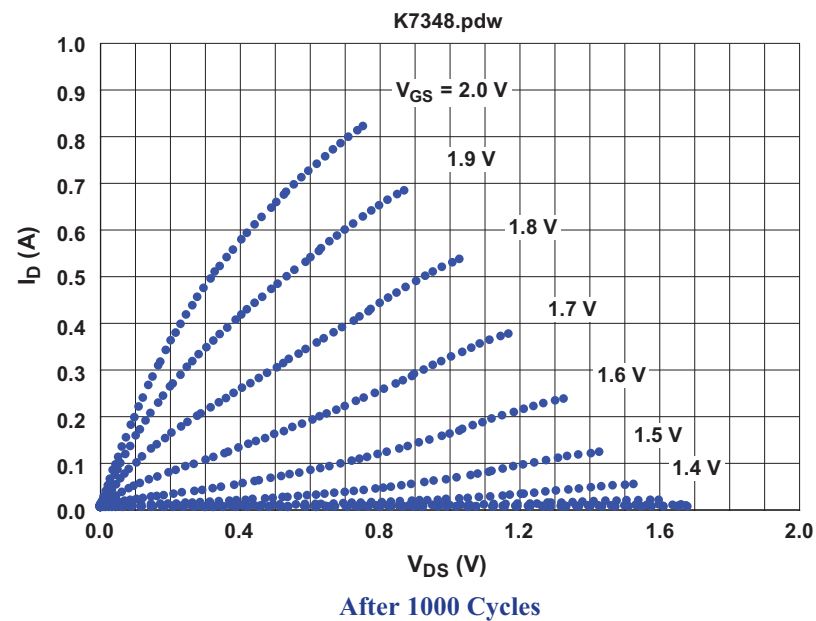
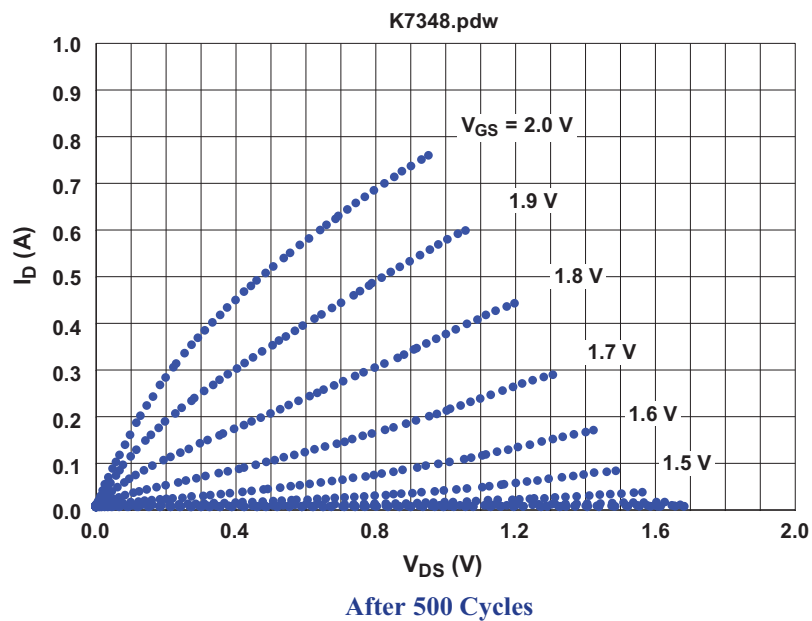
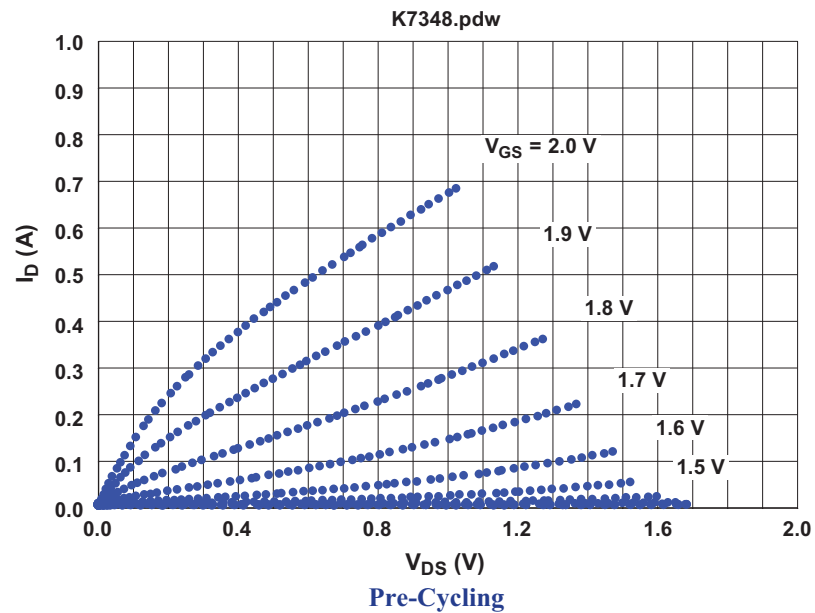


I-V Curves for A4759 (control EPC2012)



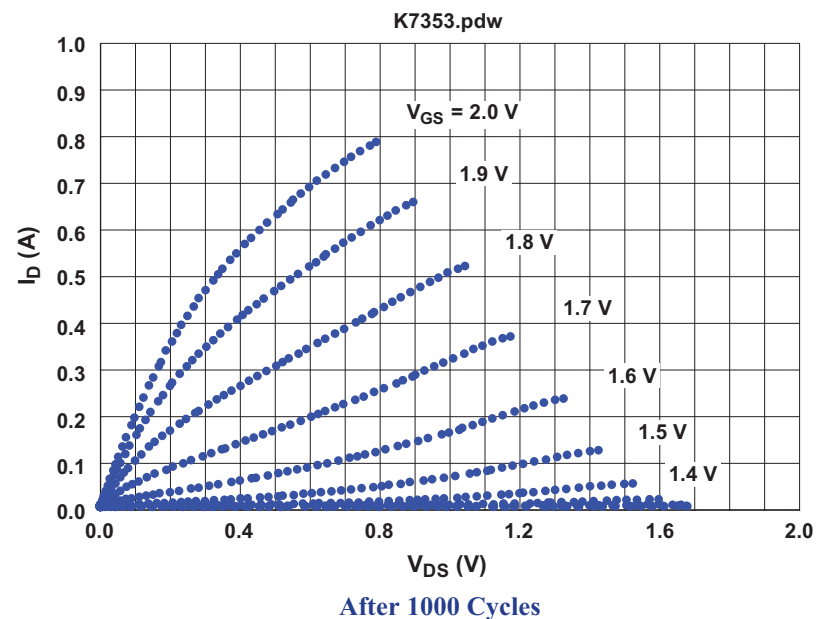
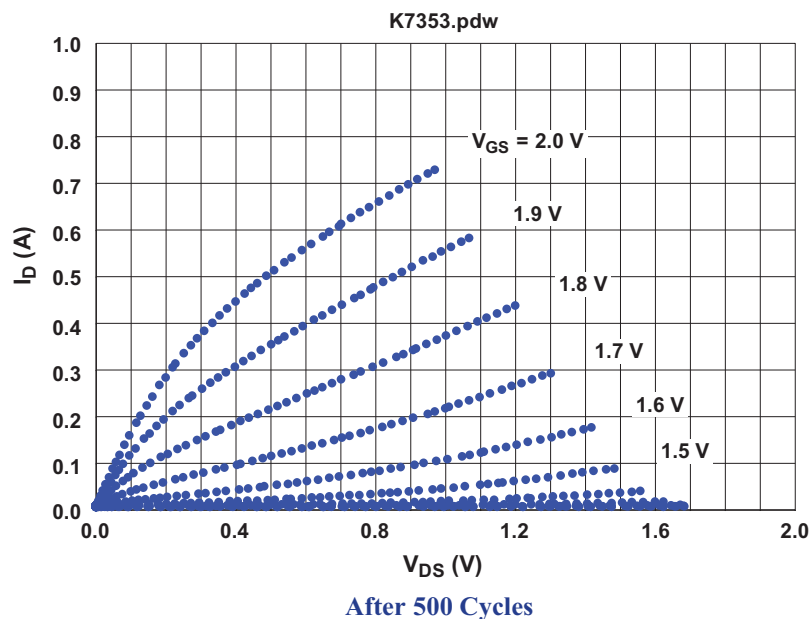
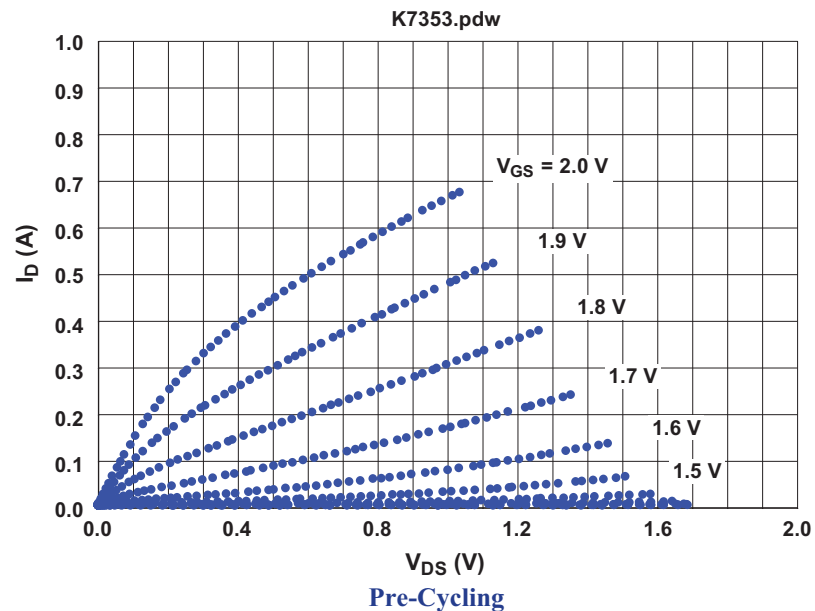


I-V Curves for K7348 (irradiated EPC2012)



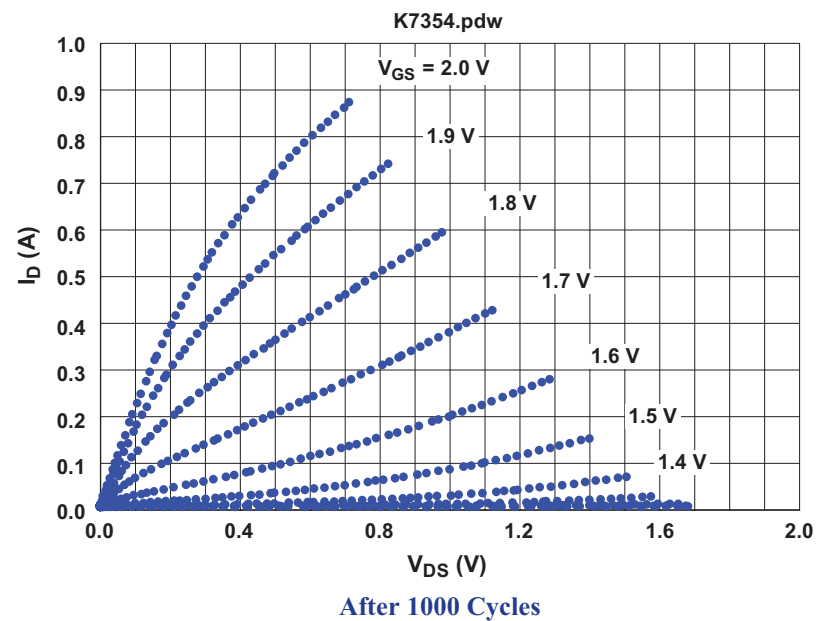
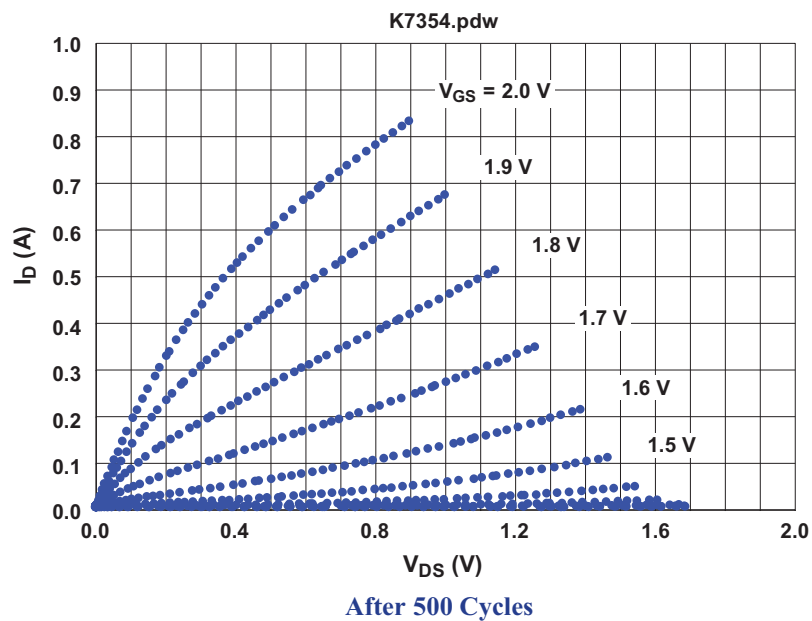
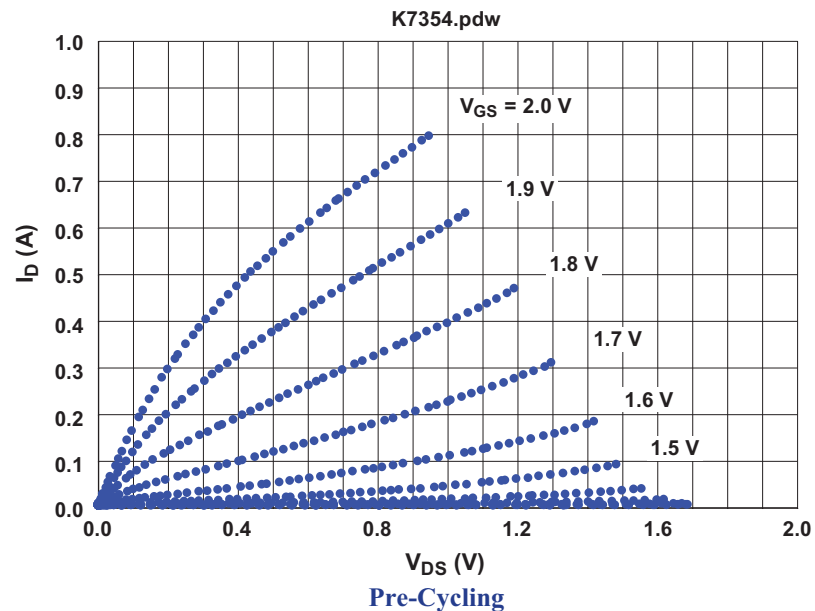


I-V Curves for K7353 (irradiated EPC2012)



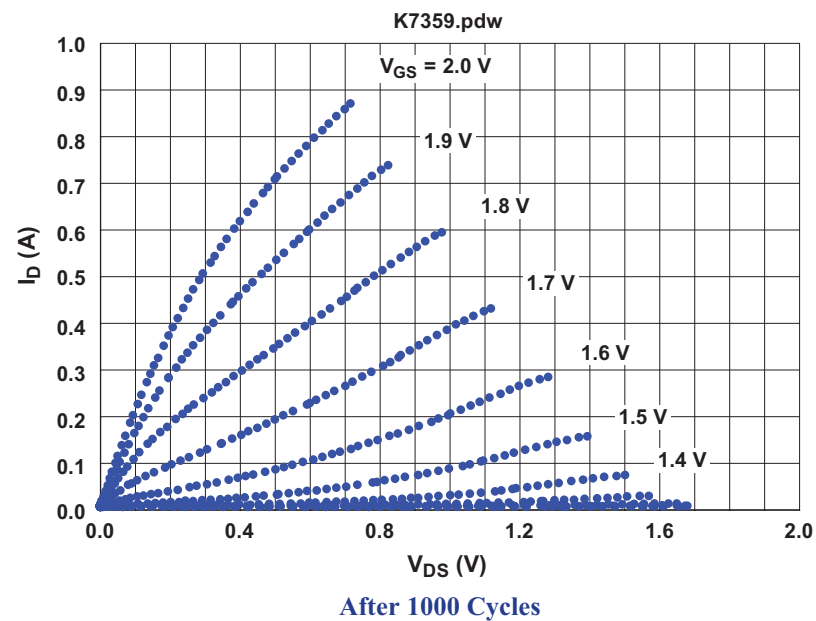
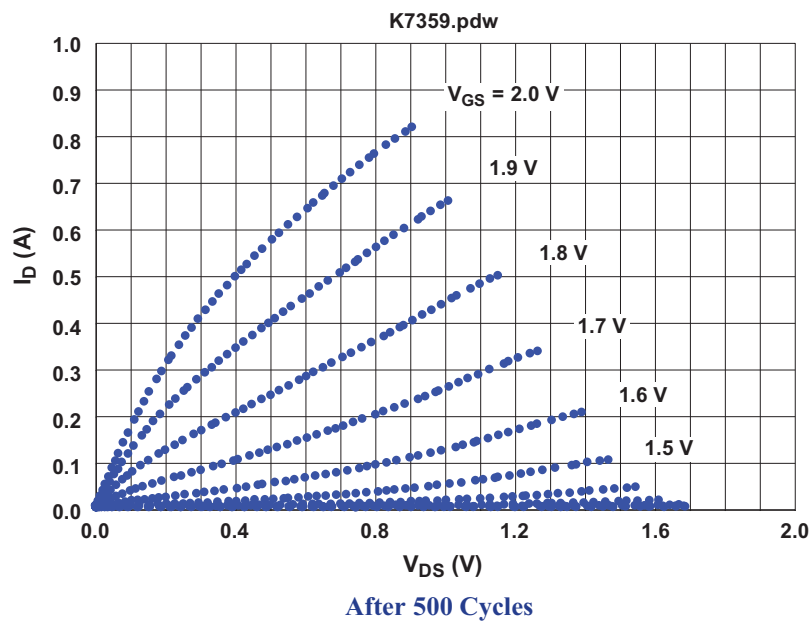
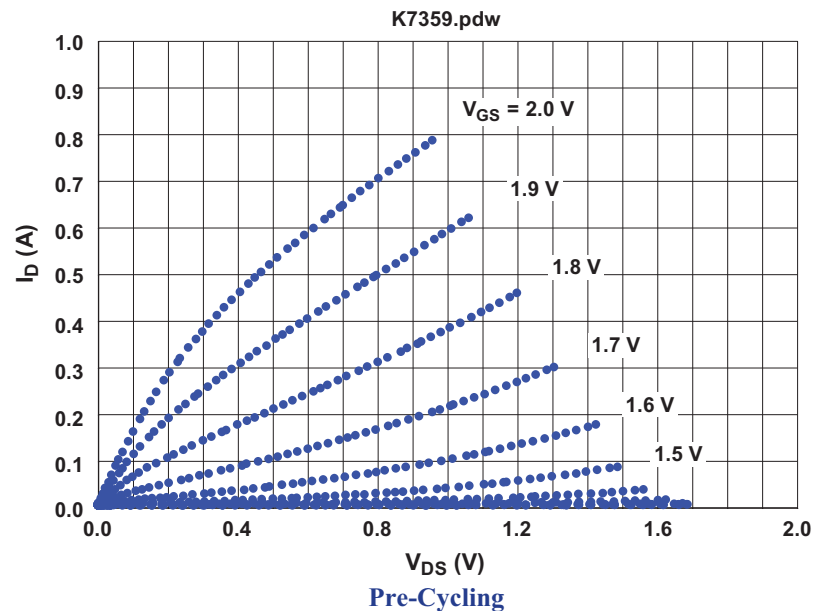


I-V Curves for K7354 (irradiated EPC2012)



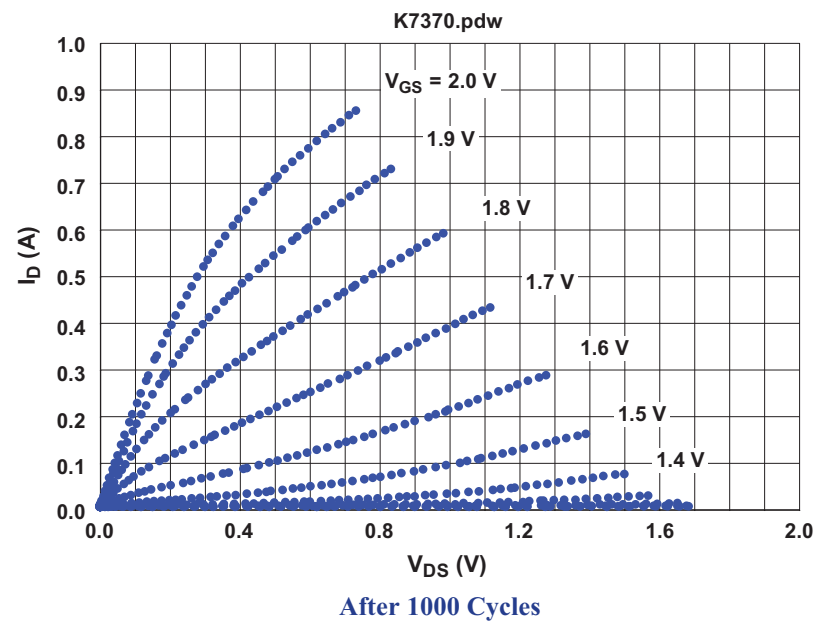
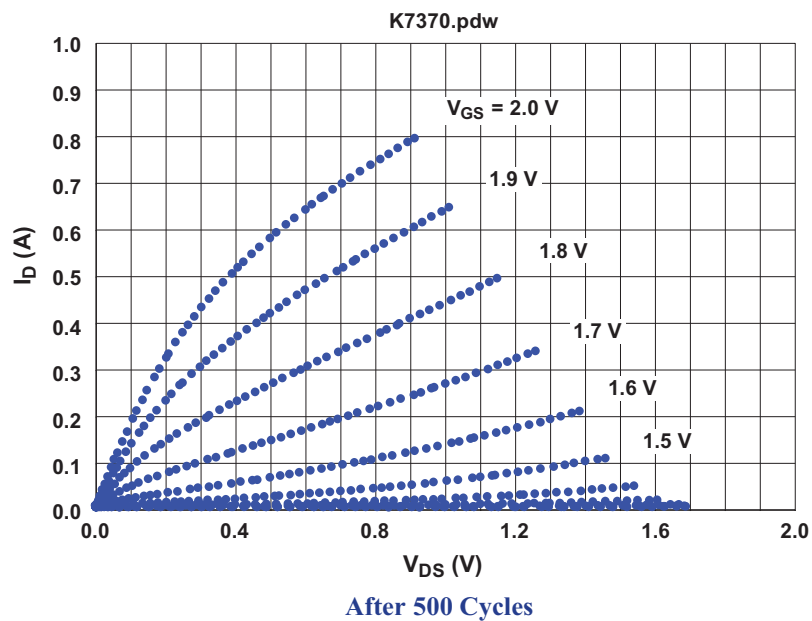
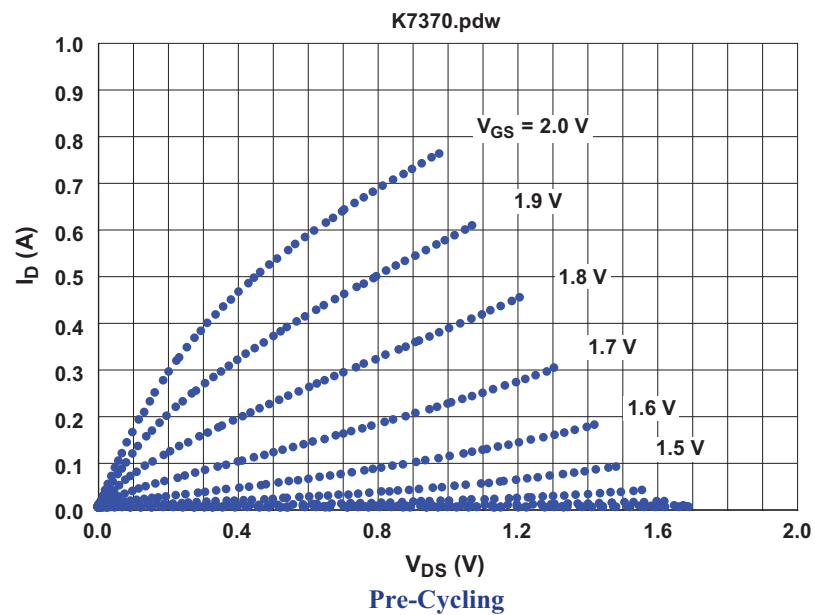


I-V Curves for K7359 (irradiated EPC2012)



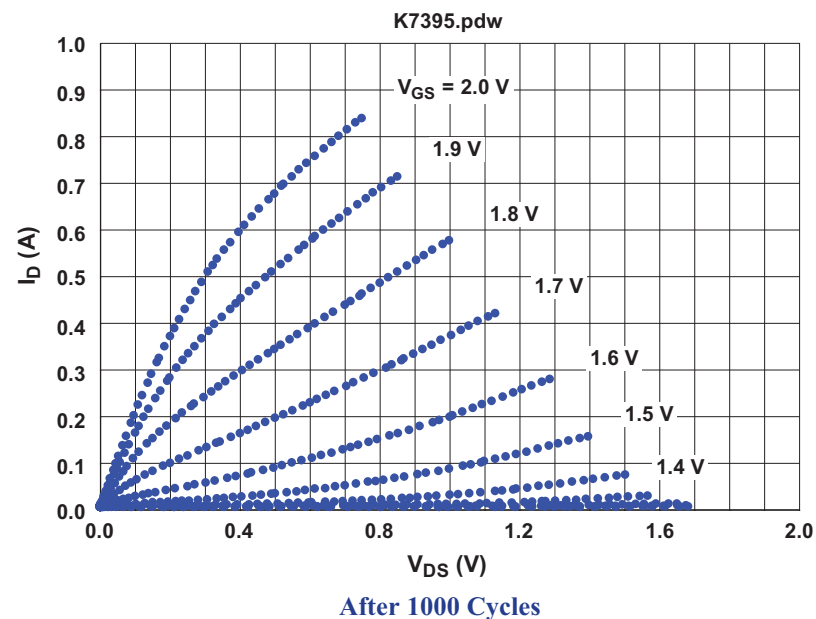
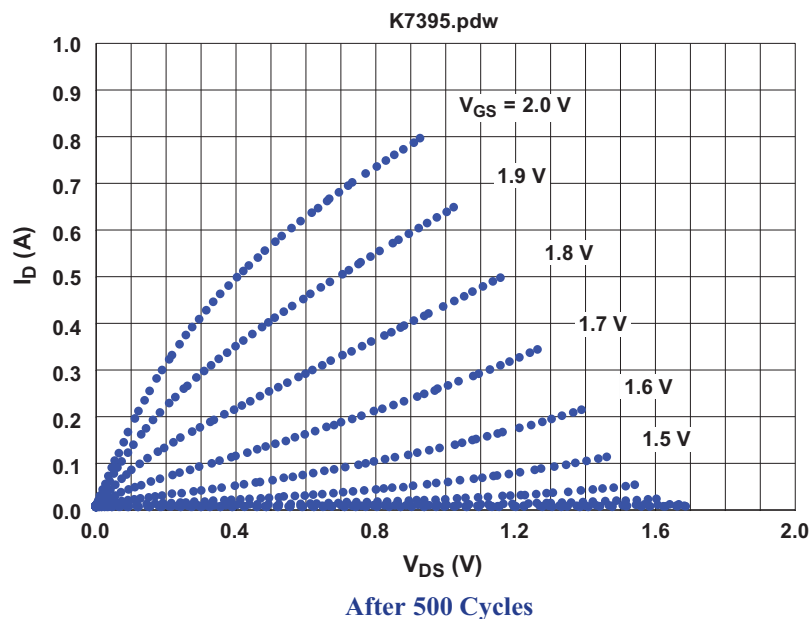
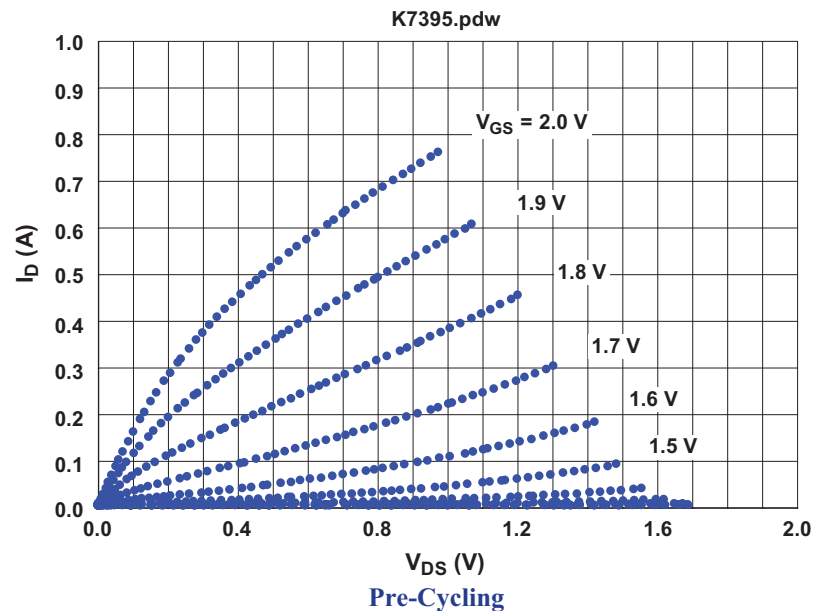


I-V Curves for K7370 (irradiated EPC2012)



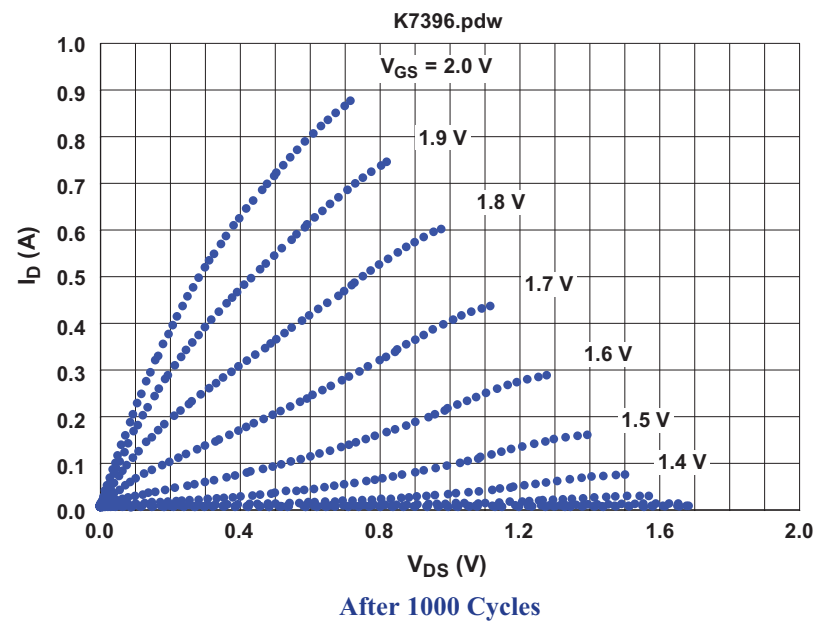
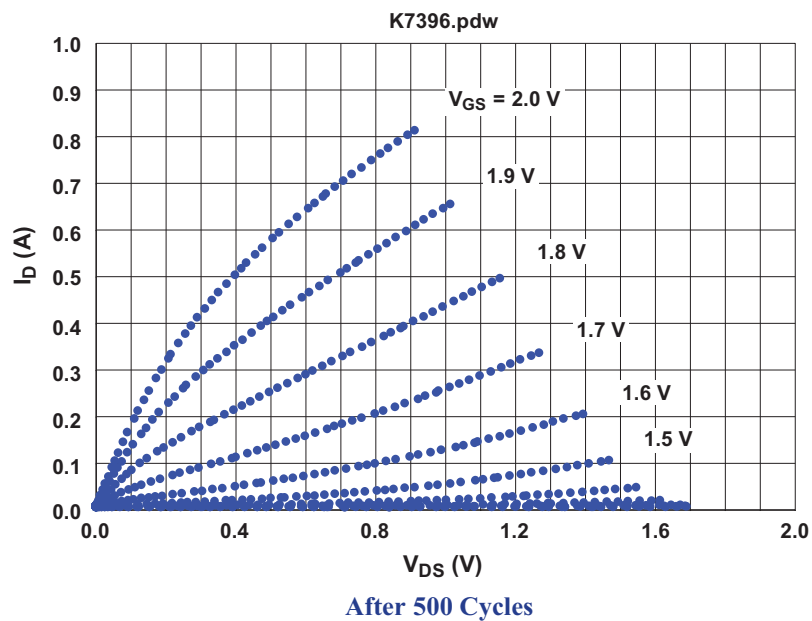
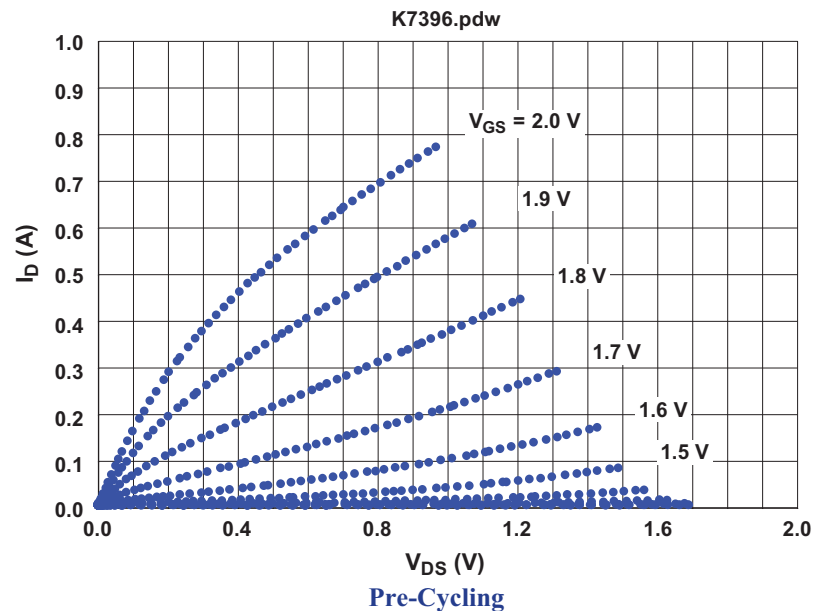


I-V Curves for K7395 (irradiated EPC2012)



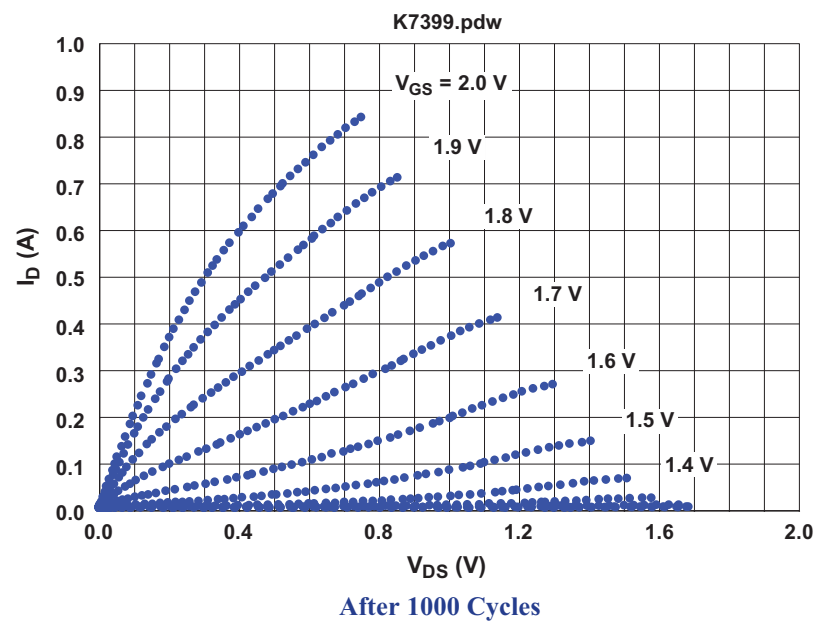
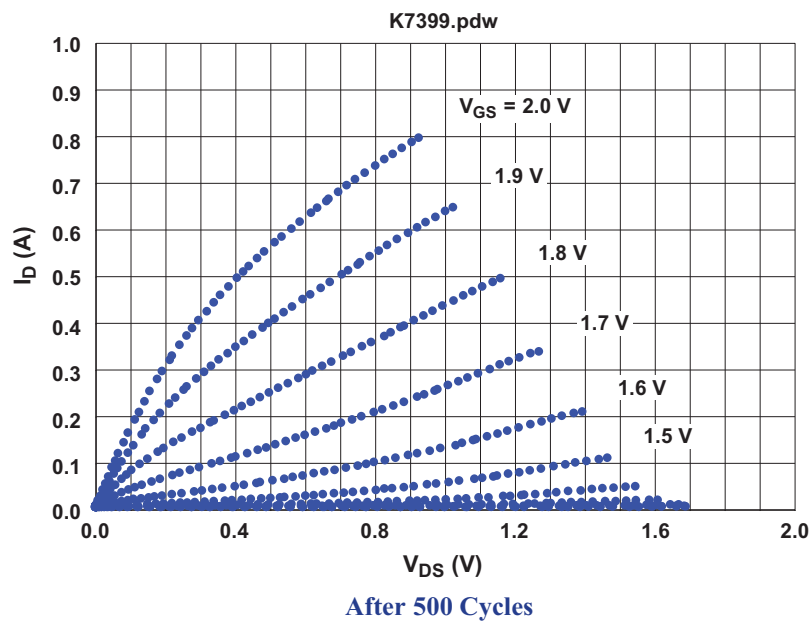
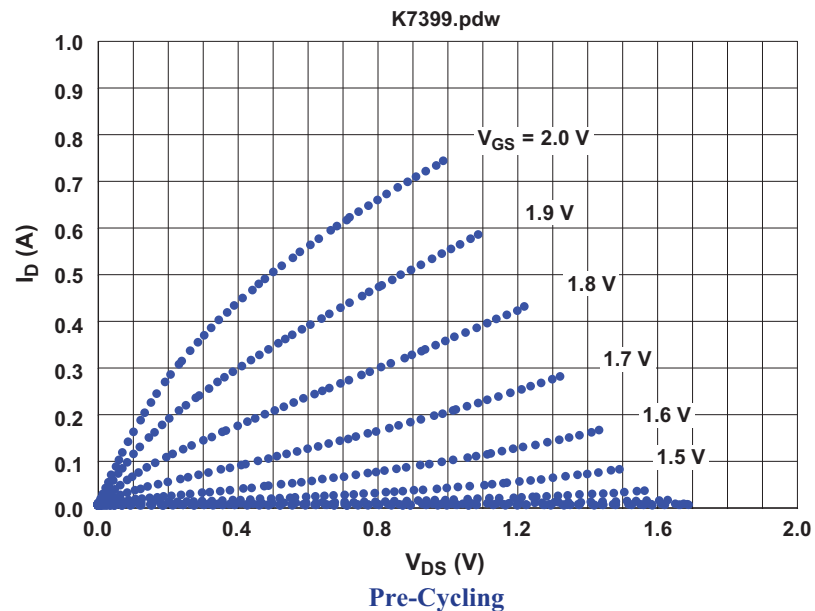


I-V Curves for K7396 (irradiated EPC2012)



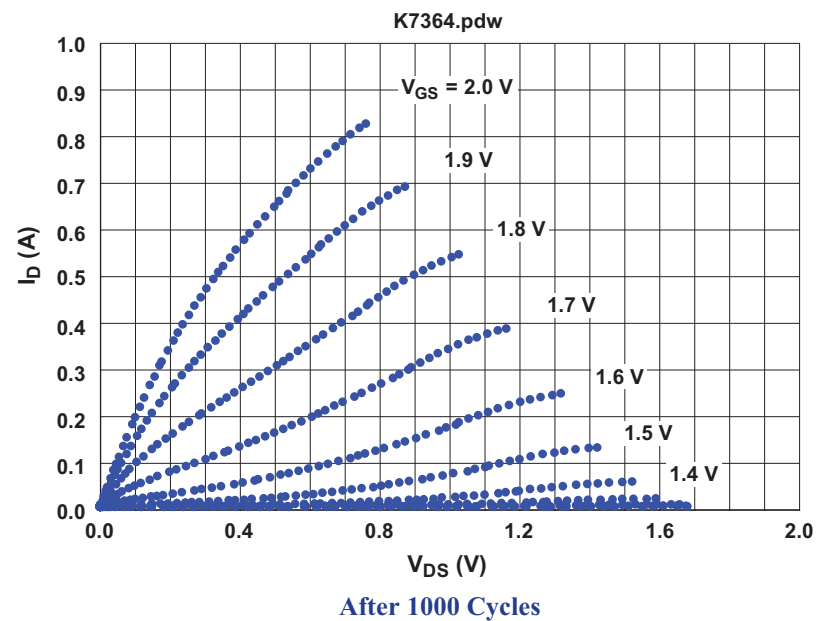
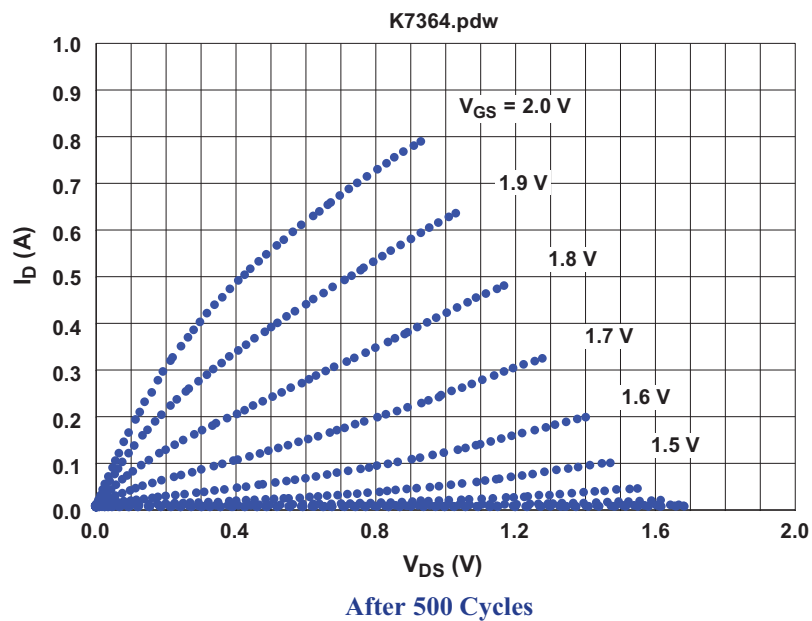
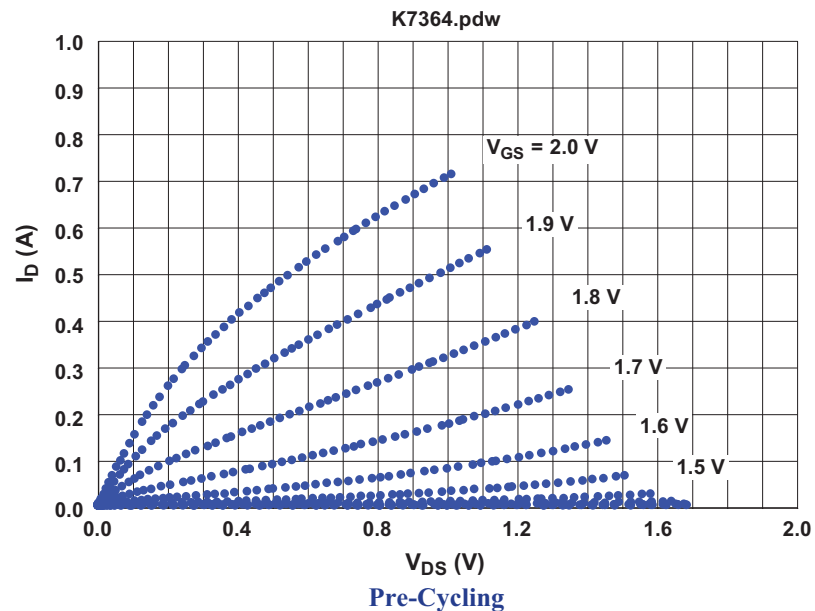


I-V Curves for K7399 (irradiated EPC2012)





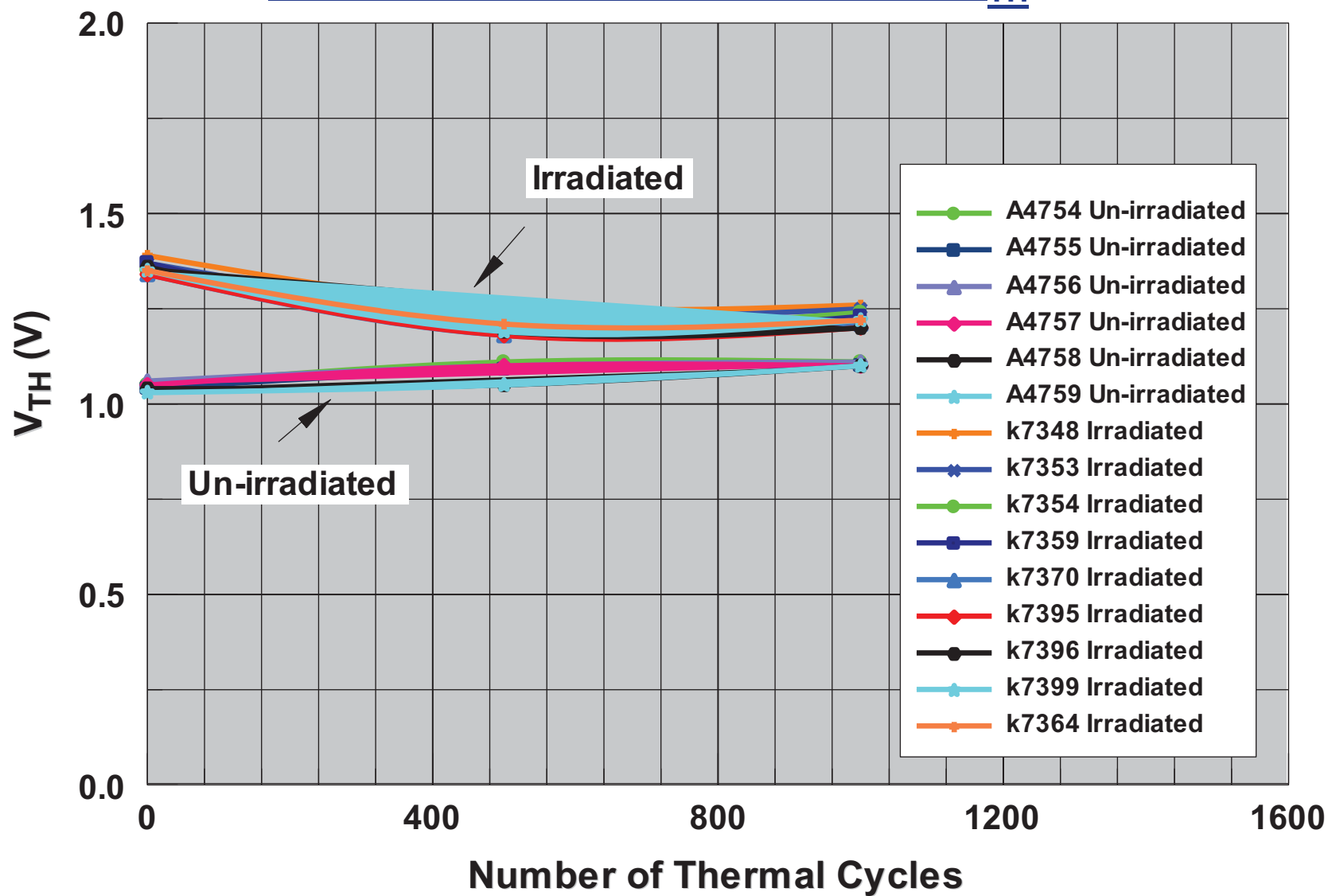
I-V Curves for K7364 (irradiated EPC2012)

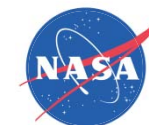




EPC2012

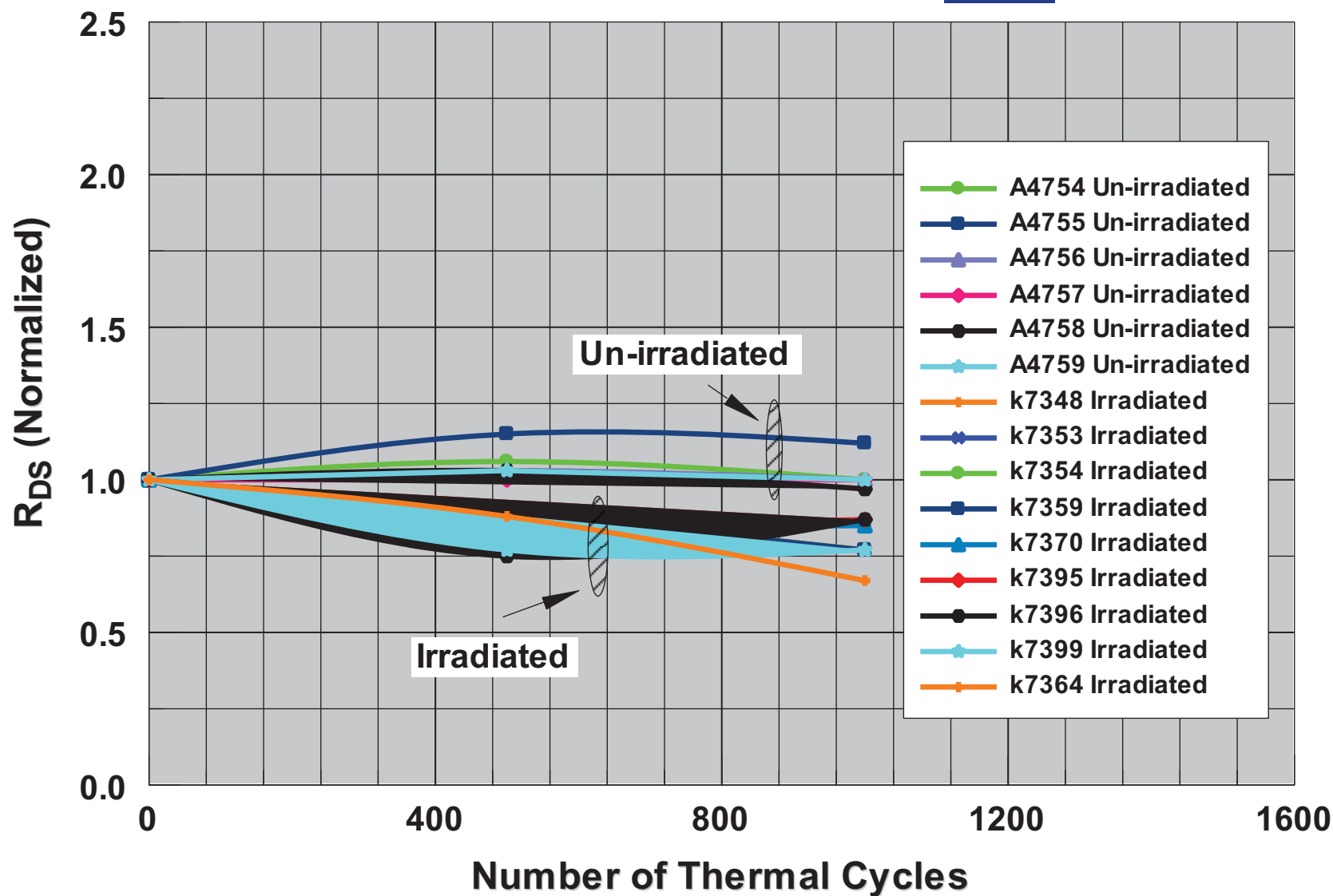
GATE THRESHOLD VOLTAGE, V_{TH}





EPC2012

Drain-Source On Resistance, $R_{DS(ON)}$





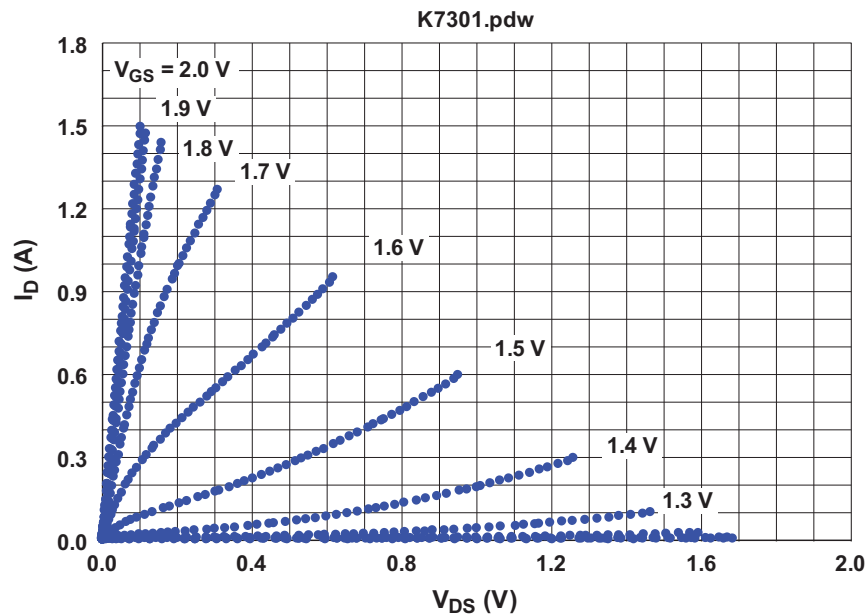
OBSERVATIONS

- All fifteen EPC2012 GaN transistors, control & irradiated, remained functional after exposure to radiation followed by 1000 thermal cycles between -55 & +125 °C
- Radiation seemed to affect steepness of the I-V curves as reflected by the increase in V_{TH} & $R_{DS(ON)}$
- Thermal cycling seemed to influence characteristics of control as well as irradiated samples:
 - While V_{TH} of control parts increased slightly with cycling, those of the irradiated parts exhibited a decrease
 - No effect on $R_{DS(ON)}$ of majority of control parts but a decrease in this property was observed for the irradiated counterparts
- Part-to-part variability apparent in output characteristics
- No alteration in device packaging or terminations

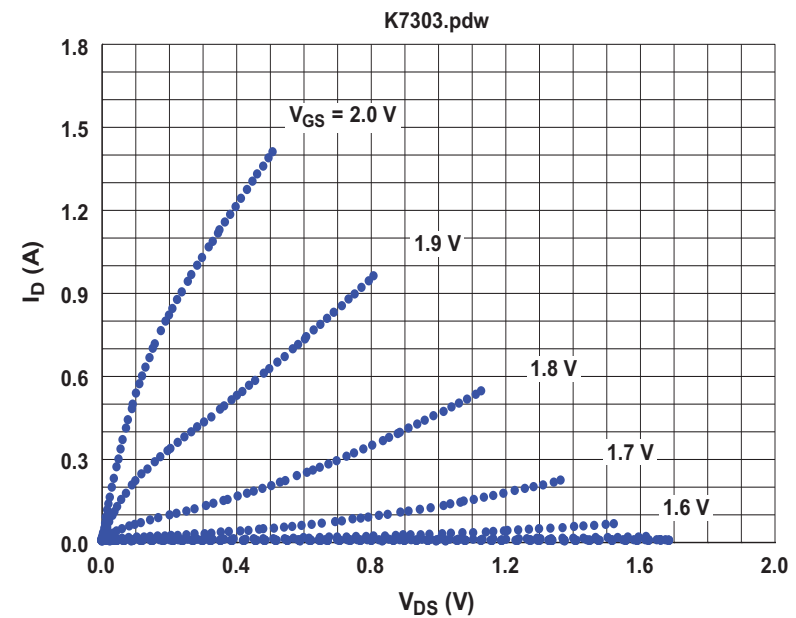


Second Gen GaN FET

EPC2015 GaN FET (40V, 33A, 4mΩ), Precycling @ 20 °C



Control

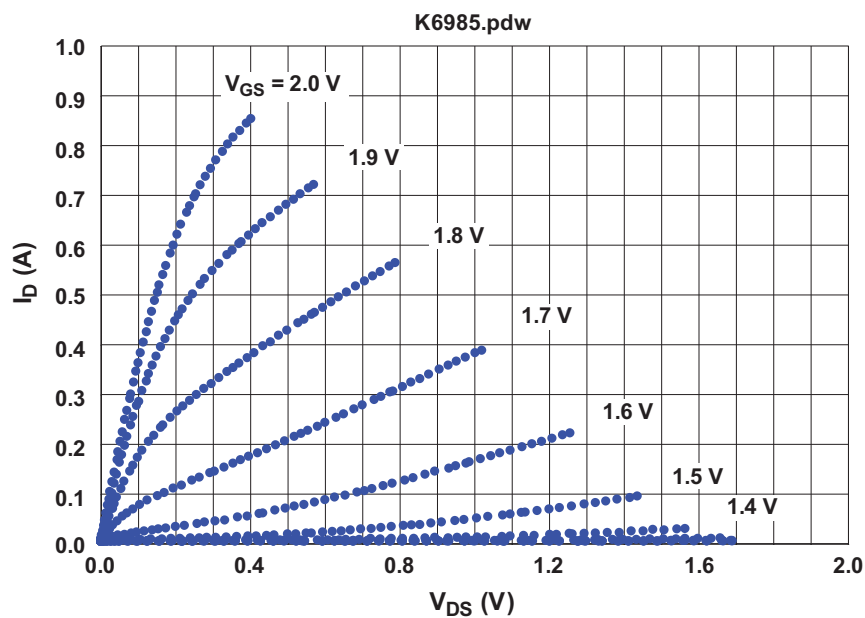


Irradiated

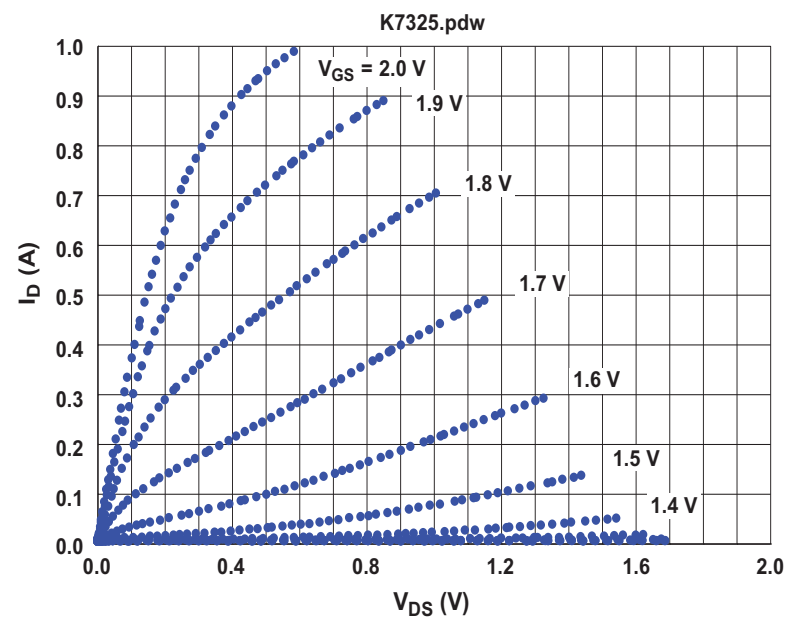


Second Gen GaN FET

EPC 2014 GaN FET (40V, 10A, 16mΩ), Precycling @ 20 °C



Control

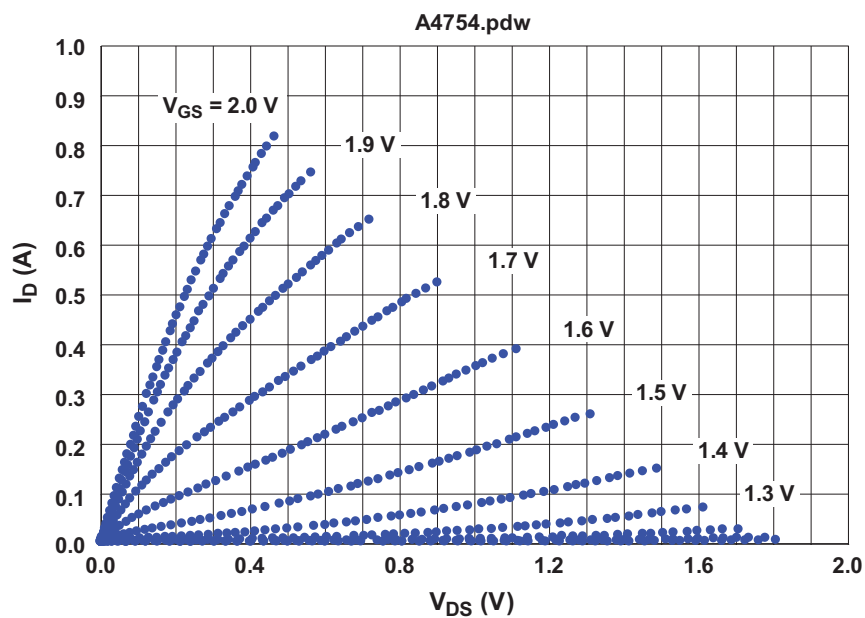


Irradiated

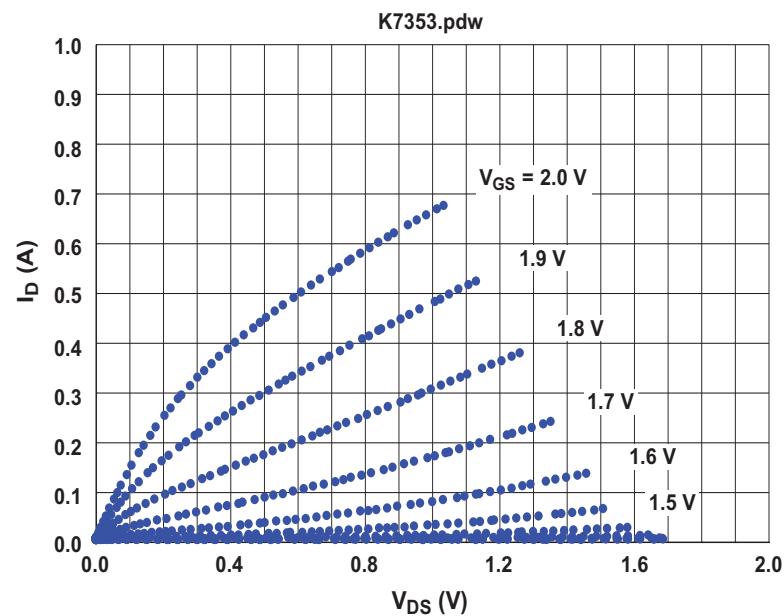


Second Gen GaN FET

EPC 2012 GaN FET (200V, 3A, 100m Ω), Precycling @ 20 °C



Control



Irradiated



Planned Work

- Conduct multi-stress tests (electrical/thermal) on these control and irradiated GaN & SiC power devices
- Perform overstress tests to determine failure mechanisms
- Repeat work on newly-developed GaN and SiC COTS power devices in support of NEPP Program



ACKNOWLEDGMENT

This collaborative work was performed in support of the NASA Electronic Parts and Packaging Program. Guidance and funding provided by the Program's co-managers Michael Sampson and Kenneth LaBel are greatly appreciated. Part of this work was done at the NASA Glenn Research Center under GESS-3 Contract # NNC12BA01B.